Tappi

PUBLISHED BY THE TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRY

DECEMBER 1954

VOLUME 37 • NUMBER 12

to our old customers

Thank you for your confidence in our products.

to our new customers

A hearty handshake and our promise to produce felts which will merit your continued patronage.

to our returning customers

Welcome home! Huyck expanded services are geared to help you.

a very merry christmas

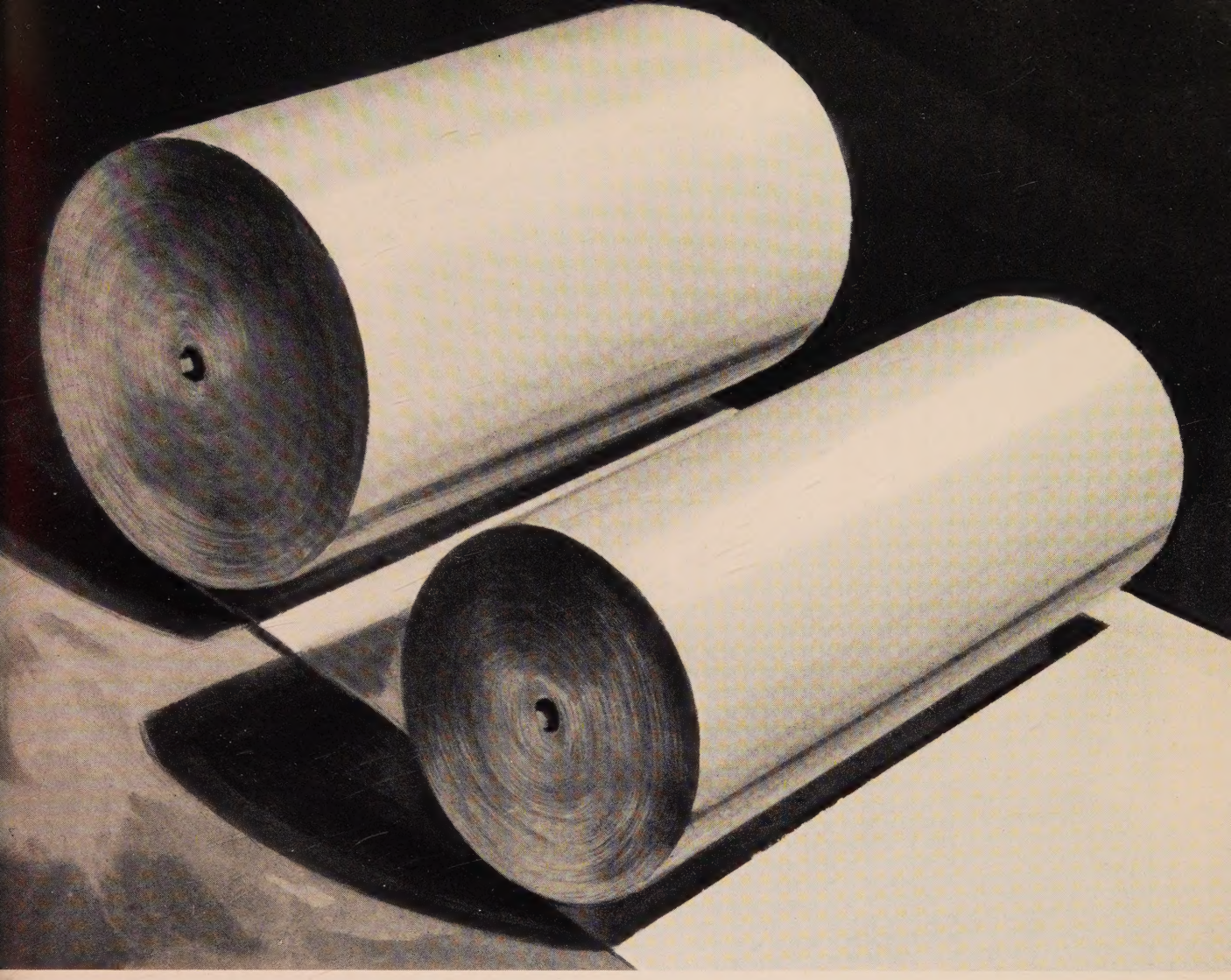
and a prosperous Happy New Year **to all our friends**

KENWOOD TEXTILE PRODUCTS

HUYCK FELTS

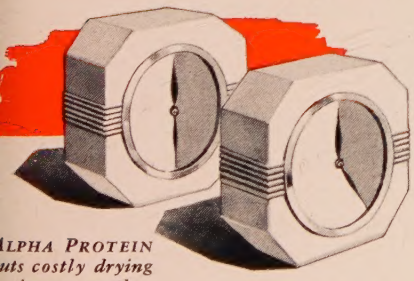
"First in Quality . . . First in Service"

F. C. HUYCK & SONS, RENSSELAER, N. Y.



roduction increased up to 15% with Alpha Protein®

...THE HIGH SOLIDS COATING ADHESIVE FOR OFFSET PAPERS



LPHA PROTEIN uts costly drying time as much as 15%.

Solids in coatings increased up to 12% by ALPHA PROTEIN

It's the extra solids in an Alpha Protein formulated adhesive which make possible production increases as much as 15%. More solids mean fastest drying, highest machine speeds. In addition, Alpha Protein improves printability, increases water resistance, gives greater uniformity and assures sharper reproduction. If you wish, the Glidden specialists in paper manufacturing will pilot test Alpha Protein to your requirements. This way they can make recommendations from laboratory and field experience long before you tie up any of your costly production equipment. Call Glidden for fast, competent service on all of your high solids coating needs.

This advertisement is printed on paper processed with Glidden Alpha Protein. It is typical of the superior reproduction that can be obtained.

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QUALITY Glidden PRODUCTS

Chemurgy Division

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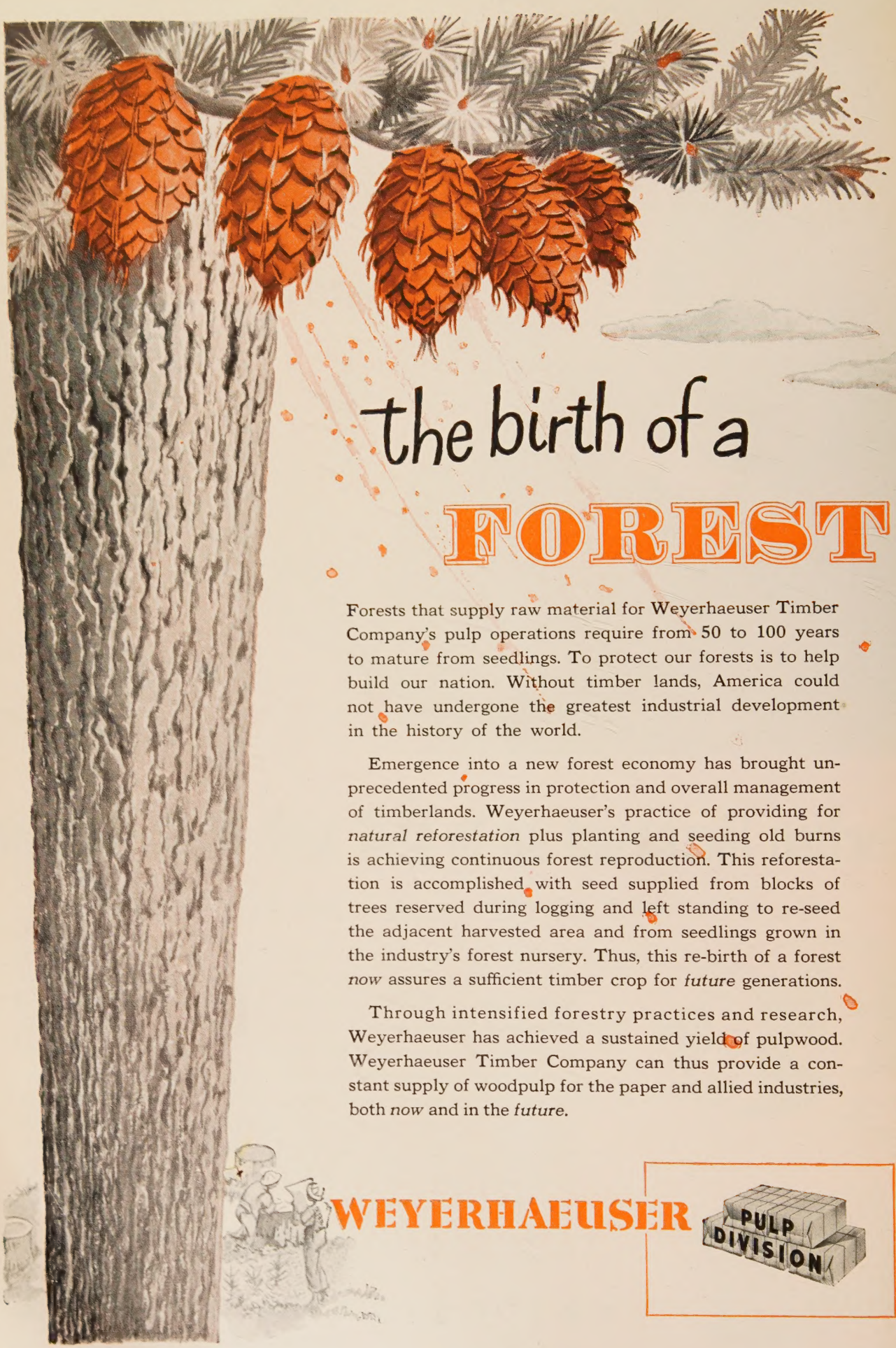


the birth of a FOREST

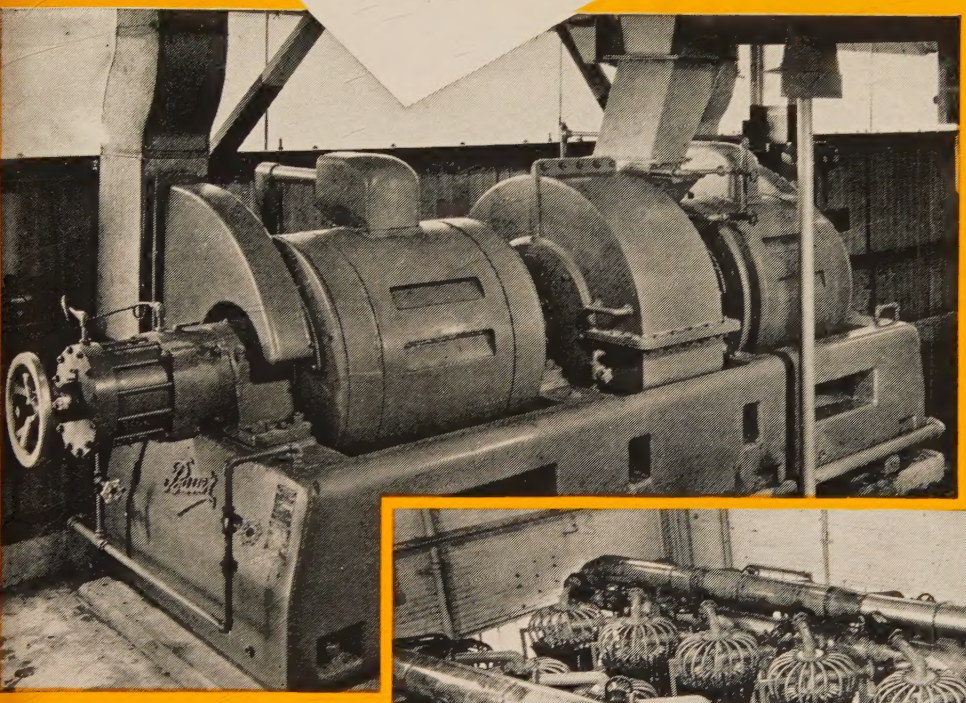
Forests that supply raw material for Weyerhaeuser Timber Company's pulp operations require from 50 to 100 years to mature from seedlings. To protect our forests is to help build our nation. Without timber lands, America could not have undergone the greatest industrial development in the history of the world.

Emergence into a new forest economy has brought unprecedented progress in protection and overall management of timberlands. Weyerhaeuser's practice of providing for *natural reforestation* plus planting and seeding old burns is achieving continuous forest reproduction. This reforestation is accomplished with seed supplied from blocks of trees reserved during logging and left standing to re-seed the adjacent harvested area and from seedlings grown in the industry's forest nursery. Thus, this re-birth of a forest *now* assures a sufficient timber crop for *future* generations.

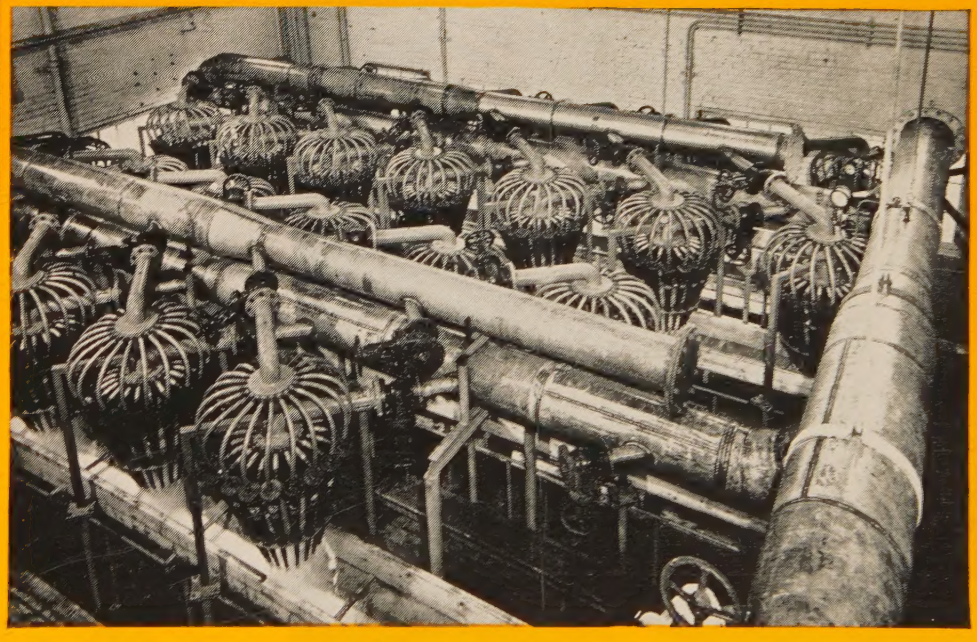
Through intensified forestry practices and research, Weyerhaeuser has achieved a sustained yield of pulpwood. Weyerhaeuser Timber Company can thus provide a constant supply of woodpulp for the paper and allied industries, both *now* and in the *future*.

WEYERHAEUSER

GUARANTEED QUALITY OF SEMI-CHEMICAL PULP *with BAUER REFINERS plus BAUER CLEANERS*



Bauer Double
Revolving Disc Refiner
in a Southern Paper Mill



Clusters of
No. 600 Bauer Cleaners
in a Canadian Pulp Plant

A COMBINATION YOU CAN'T BEAT!

We have the experience and the understanding, as well as the equipment to design your complete pulp processing plant.

HE BAUER BROS. CO. • 1715 Sheridan Ave. • Springfield, Ohio

Bauer

it may help you!

Titanium is a metal the world has known for a long time—and now you can put its unusual combination of valuable properties to work for you in the form of Carpenter Titanium Tubing.

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Carpenter Titanium Tubing is highly resistant to most corrosives, salt water and salt atmospheres. Its extreme resistance to erosion and cavitation is unique among metals. Yet, with all this, Carpenter Titanium Tubing is ductile, may be successfully machined.

With all these desirable characteristics—in combination—it may be that Carpenter Titanium Tubing can help you solve a number of design and production problems.

If you would like more information about Carpenter Titanium Tubing, and its place in your product or plant, write today to:

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The Carpenter Steel Company,
Alloy Tube Division, Union, N.J.

Export Dept.: The Carpenter Steel Co., Port Washington, N.Y. "CARSTEELCO"

Carpenter

more than corrosion resistance

Stainless Tubing & Pipe

DECEMBER 1954

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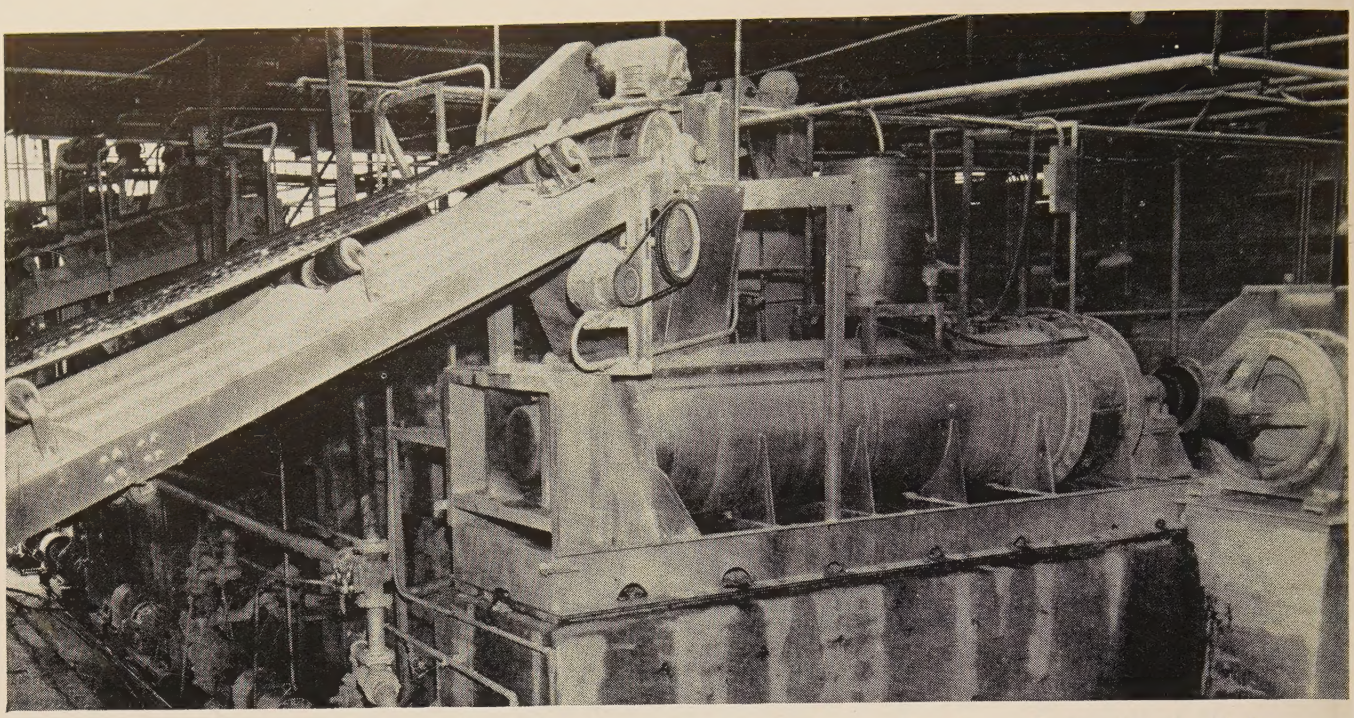


Huge pugmill in unique Huber patented process breaks down clay particles into smaller sizes, reducing viscosity of clay-water mixture. This process simplifies the control of paper coating operations.

Revolutionary Research Development by Huber's Clay Division Transforms Clay Particles to Control Clay Viscosity

VISCONTROL *The Unique Patented Process for the Control of Coating Clay Viscosity*

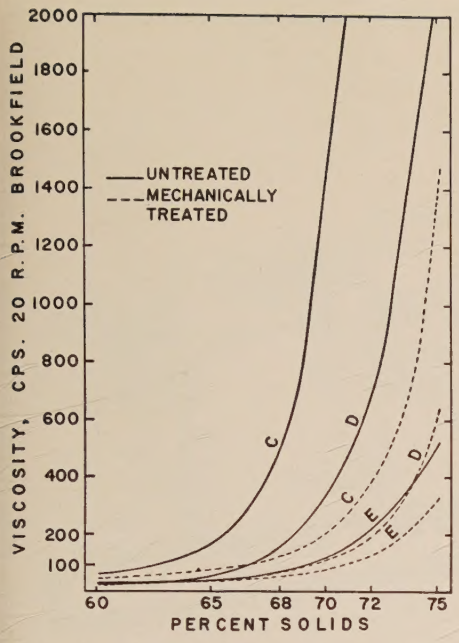
NEW YORK, N. Y.... Reports from the paper industry indicate that the method for controlling clay viscosity developed by J. M. Huber Corporation is highly successful and has significantly reduced the problems associated with modern high speed coating operations. The method, which mechanically alters the size of clay particles, was first described in a paper entitled "Viscosity Control of Concentrated Clay Suspensions" by N. Millman, technical director of Huber's Clay Division. It was published in "Paper Trade Journal," Feb. 16, 1951, and has now been thoroughly field tested.

What Controlled Viscosity Does—Using clays of controlled viscosity simplifies mill operation for the paper maker. Faster and more uniform production result. Fewer machine and formulation adjustments are needed to obtain uniform drying. Quality control problems on the finished coated sheets are reduced. And the finished sheet tends to yield a better printing job with respect to waviness and other spread and levelling complications. To show how closely J. M. Huber is able to control clay viscosity within specified ranges, car-by-car checks were kept on 100 carloads shipped to one manufacturer. Ninety-six cars fell within the 145-195 cps (Brookfield, 70% solids, 20 rpm) range. A second mill with other requirements reports that of 60 carload shipments, 58 fell within 105-125 cps.

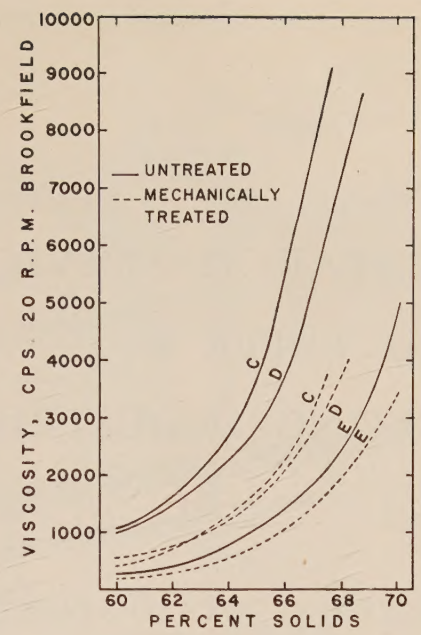
Background—To understand how the new Huber process works, it is first necessary to examine briefly the nature of the problem. The behavior of concentrated clay coating mixtures during their preparation within a plant and during their subsequent application to the surface of a rapidly moving paper web, depends considerably on the flow characteristics of the clay. Hence clay producers strive to produce a clay of definite and uniform viscosity properties.

Previous to Huber's discovery, this uniformity could be achieved in a limited fashion only through the careful selection of desirable crude clays. This process is difficult and costly due to wide differences in the flow characteristics of crude clays even from the same deposit. Hence J. M. Huber decided to concentrate its research efforts for clay uniformity on methods that would alter the inherent properties of the crude clay.

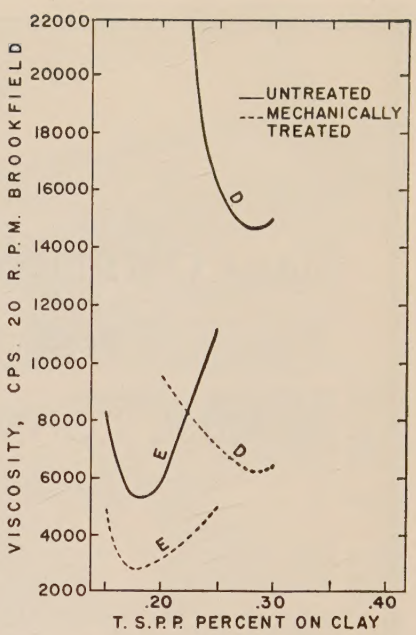
Industry Requirements—Machine coating of paper by modern methods generally requires coating colors of high



Viscosity of treated and untreated clays in deflocculated clay-water suspensions. Treatment in all cases shown was in the Huber pugmill.



Viscosity of treated and untreated clays in starch coating colors. The starch was converted and blended with the dispersed mixture.



Viscosity of treated and untreated clays in coating colors prepared by converting starch in the presence of clay.

solids content. Frequently clay-water suspensions containing as high as 72 per cent clay are required to flow freely through relatively fine screens. Also, coating colors in some cases containing in excess of 65 per cent total solids, must be of a character which will permit spreading at coating machine speeds and levelling after application to the paper surface. Sometimes the clay acts as a limiting factor because of the high viscosity it imparts to coating mixtures.

What Affects Viscosity?—Particle size alone does not determine the viscosity of a clay suspension. The lowest viscosity clays are those whose structural arrangement of particle size and particle shape is such as to produce the least impediment to particle rotation in a relatively small volume of liquid.

The shape of the clay particle has a controlling influence on the viscosity of the suspension. Particles suspended in a flowing liquid are rotated because of the unequal velocity of the flow planes on each side of the particle. If the particles become too crowded they interfere with free rotation and the flow is retarded. For free rotation, Huber researchers found that the particle should be suspended in a sphere of liquid which would enclose the particle. If the particle is spherical, the volume required for free rotation would be that of the particle itself. If the particle is needle shaped, the volume of liquid required would be a sphere the diameter of which is equal to the length of the needle. The more the shape of the clay particle departs from that of a sphere, the greater the volume of liquid required for free rotation in proportion to the volume of solid of the particle. It follows then that any change in the shape of clay particles caused by breaking across needle or plate-like crystals, while increasing fineness, might be expected to produce a reduction in viscosity of highly concentrated suspensions.

How It Is Done—The most practical method of breaking up the clay particles consists of mechanically working a crude clay body of putty-like consistency. The mixing should be sufficiently rapid so that the plates are broken as they interfere in passing in adjacent slip streams. This action produces clay of increased fineness composed of particles having a greater ratio of thickness to length and, at the same time, tends to produce a closer packed mixture of different sized particles.

The process is carried on by J. M. Huber in a continuous manner with a strongly constructed pugmill into which the proper amounts of crude clay, water and deflocculent are fed. Such equipment operating at about 30 h.p. hours per ton of clay will produce a marked decrease in the inherent viscosity of the clay in concentrated clay suspensions. After pugmill treatment, the crude clay can be diluted and subjected to various methods of fractionation to effect the separation of clays of varying particle fineness. Comparative viscosity of treated and untreated clays are shown in the figures. Working samples of controlled viscosity clays are available from J. M. Huber Corp., 100 Park Ave., N. Y. 17, N. Y.

J. M. HUBER CORPORATION, 100 PARK AVENUE, NEW YORK 17, N. Y.

One of the World's Largest Clay Producers

HUBER

A COMPLETE STARCH SERVICE FOR THE PAPER & PAPER CONVERTING INDUSTRIES

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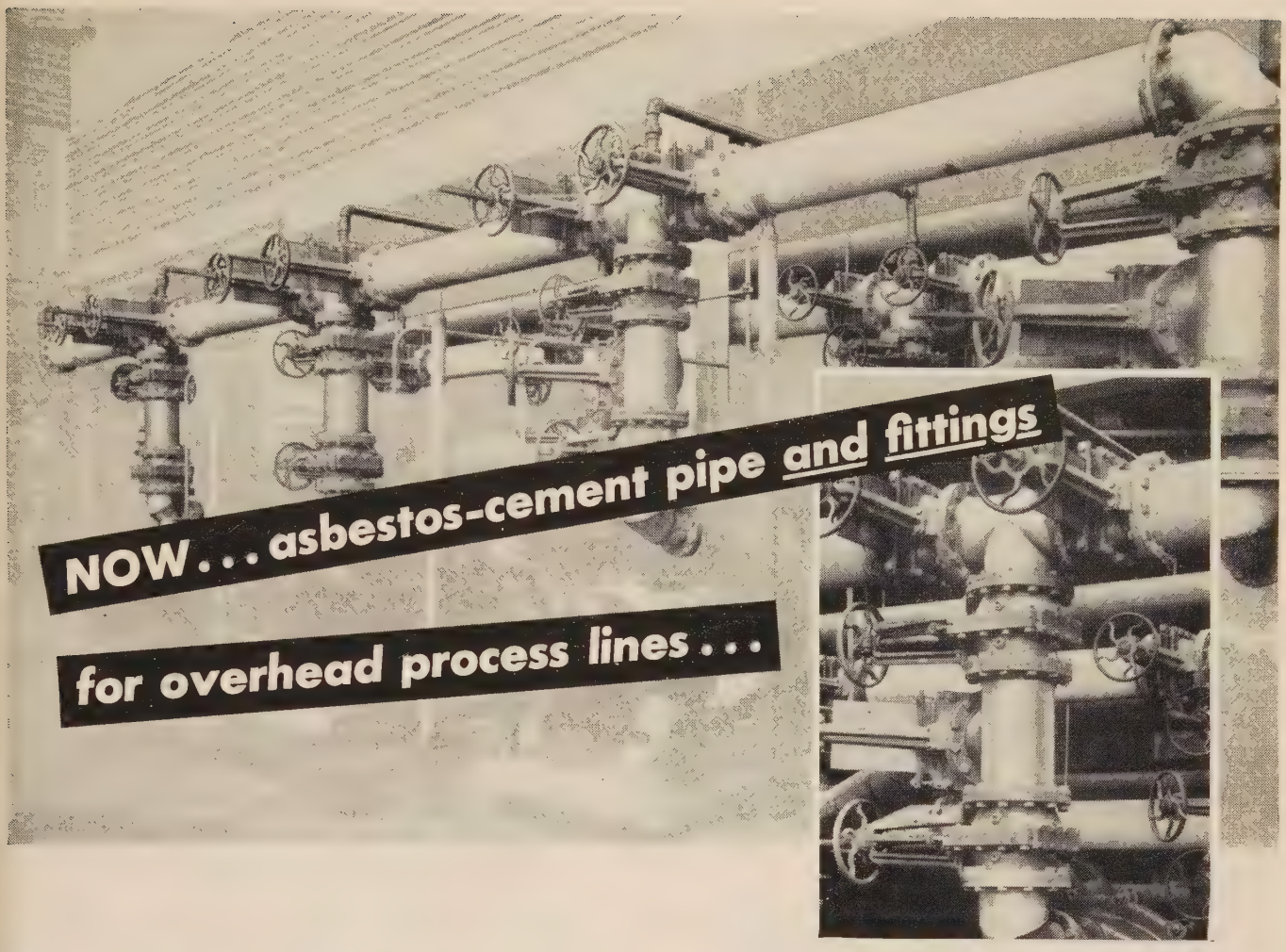
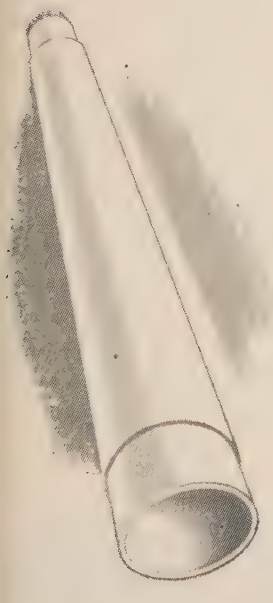


Transite Pressure Pipe provides high carrying capacity and economical, efficient service...



You can now obtain Transite* asbestos-cement Pressure Pipe with Transite-lined Streed Fittings for your overhead process systems. This permits the installation of high strength non-metallic pipe for handling raw and treated water, washed and unwashed pulps, stocks of all kinds, multi-stage bleaching systems (except direct chlorination) and certain mill wastes. There is no better way to provide clean pulp and stock than by handling it through Transite Pressure Pipe.

Low installation costs—Transite is light in weight, easy to handle, and can be drilled, cut, threaded and machined with standard tools. *And*, because its carrying capacity stays high, you can specify the smallest diameter pipe necessary . . . thus making the minimum capital investment.

Low pumping costs—Transite Pressure Pipe offers exceptionally low frictional resistance to the flow of liquids (flow coefficient C=140 for water). Since it is resistant to sliming and bacterial growths, this high carrying capacity is continuously maintained so that pumps can be operated at maximum efficiency and lowest cost.

Low maintenance costs—Transite cannot rust and is highly resistant to the corrosive action of mild acids and alkalies. Consequently, it requires a minimum of maintenance throughout its long life.

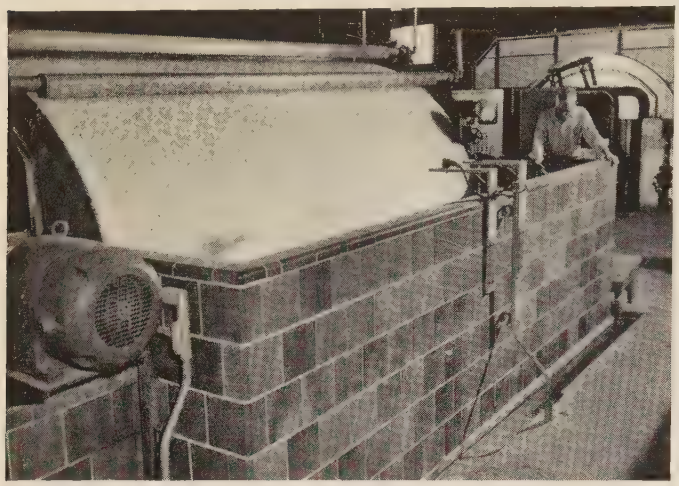
For underground service too, such as water supply or fire lines, Transite Pressure Pipe offers the same outstanding advantages. To obtain further information on Transite Pipe Systems for paper mills, write Johns-Manville, Box 60, New York 16, N. Y.

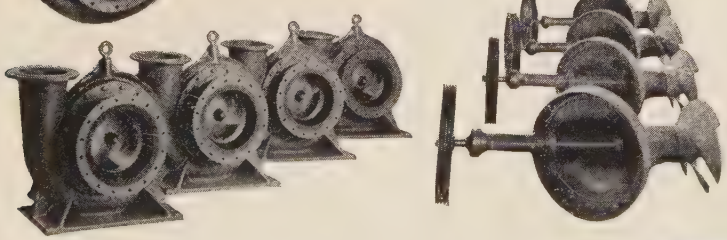
*Reg. U. S. Pat. Off.

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville TRANSITE PRESSURE PIPE

Buckeye *bleaches* with a modern Sandy Hill Kamyr Bleach System





ELEMENTS OF SANDY HILL KAMYR BLEACH SYSTEM SUCH AS INSTALLED AT BUCKEYE

Illustration at top shows bleached pulp receiving final washing on Kamyr Vacuum Washer. Other pictures, in order, are dilution nozzles and circulation, feed, transport and tangential pumps, all contributing to the high efficiency of the Kamyr Bleach System.

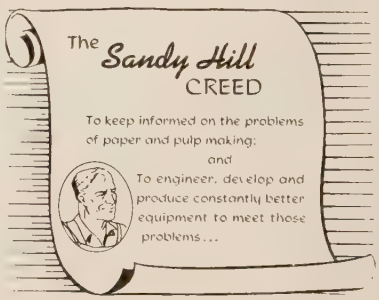
ANOTHER important chapter in the history of paper making in America is written with the opening of the new 25 million dollar high-alpha cellulose pulp mill of The Buckeye Cellulose Corporation at Foley, Florida. This completely modern plant is an impressive representative of current advances in techniques, methods and equipment. And once more Sandy Hill is proud of its opportunity and ability to cooperate with management and planners in the creation of a plant that symbolizes the highest degree of industrial progress.

The adoption of the Sandy Hill Kamyr Bleach System at Buckeye is another step in a trend that is rapidly becoming standard procedure. With steadily increasing frequency, more and more progressive mills are installing this practical, highly efficient and economical bleaching method.

At Buckeye, the Sandy Hill Kamyr Bleaching System is used to bleach high-alpha pulp to an unusual degree of brightness and purity.

The revolutionary Kamyr principles, including continuous multiple stage operation, thorough mixing and absorption of chemicals, induced strong horizontal circulation through the tangential connection of pumps, and separate washings after every treatment, are now accepted as the most effective, most dependable means for producing increased yield of more uniform pulp of higher alpha content.

By every count, the Kamyr Bleaching System produces *more* pulp, *better* pulp, *whiter* pulp, *more uniform* pulp.


The Sandy Hill CREED
To keep informed on the problems of paper and pulp making;
and
To engineer, develop and produce constantly better equipment to meet those problems...

Buckeye *produces* with a modern Sandy Hill Paper Machine

THE SANDY HILL FOURDRINIER paper machine at Buckeye is ultra modern in every detail. In the removable Fourdrinier are found all up-to-date features which contribute to extreme efficiency of sheet forming combined with a simplicity of construction and operation that lends itself to exceptional facility of adjustment.

A multiple manifold Sandy Hill Bertrams Flow Control Unit assures absolute uniformity in the distribution of stock across the wire.

The specially designed Press Section, comprising two suction presses and a smooth press, produces progressive maximum water removal. Four dryers heat the sheet between the first and second presses.

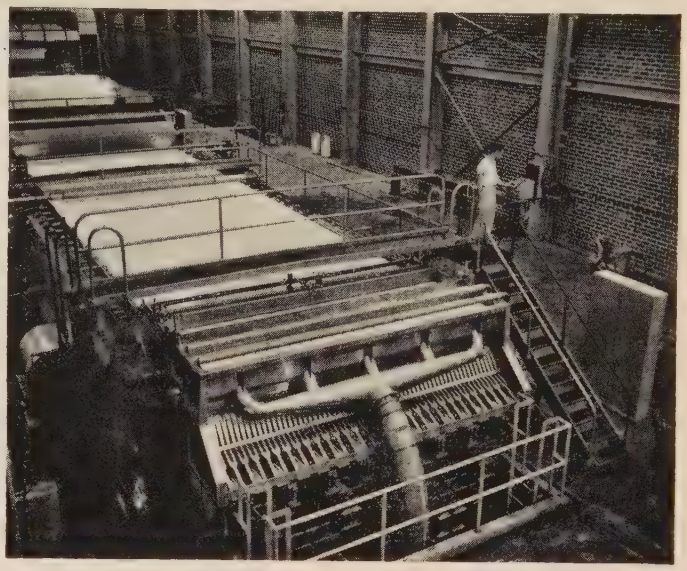
The Sandy Hill Selective Drive embodies the most modern ideas in power transmission and guarantees the machine operator's first requirement—an unvarying draw between sections.

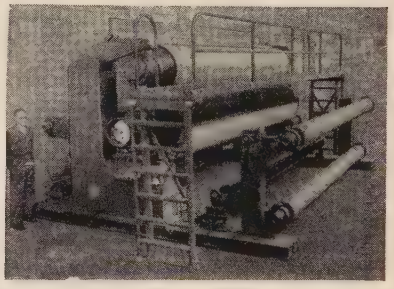
The five-foot Dryers are mounted on box-type framing in anti-friction bearings. These Dryers are constructed in the latest board machine dryer design which provides maximum convenience in working around the dryer nest.

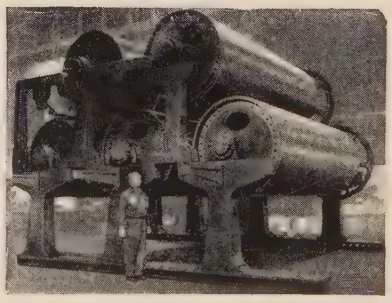
Ten ton jumbo rolls of pulp are wound on a constant speed drum reel. The rolls, both in starting and final reeling positions, are hydraulically loaded, with provision for pressure adjustment.

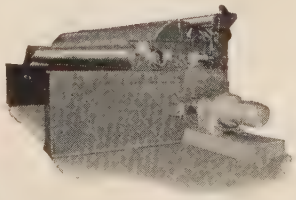
The Buckeye Fourdrinier machine incorporates the newest ideas in improved functional design combined with the integrity of construction and faithful consideration of detail that has characterized Sandy Hill equipment for generations.

Sandy Hill engineers are completely at your service in helping you plan new pulp and paper mills or improvements in existing ones.









VIEWS OF SANDY HILL EQUIPMENT DESIGNED AND BUILT FOR BUCKEYE

Illustration at top shows Fourdrinier which forms waterleaf sheet from high-alpha cellulose pulp. Following in order are first press section, dryer group and constant speed reel.

The Airveyor for unloading and conveying lime and salt cake in a paper mill.

There is a DIFFERENCE when Fuller designs and builds your conveying system

Fuller is not restricted to one design and construction but is able to select and apply the right system to conveying dry pulverized and granular materials most efficiently and economically . . . because, selection can be made from four types, or combinations, to meet conditions required: materials to be handled, capacity, distance of travel, and overall characteristics of the plant layout. In other words, each job is given individual study, before the proper equipment is selected and recommended.

Add to this, Fuller's 27 years of experience in the field of pneumatic conveying, and you have something that is hard to beat. It is something that is difficult, if not impossible, to write into specifications or show on blueprints, yet is inherent in Fuller equipment and engineering.

Fuller conveying systems can be installed without interfering with existing structures or equipment, with no production interruptions. Why not have us make a study of your conveying problems. Our findings and recommendations may give you an entirely new concept of conveying.

Write for Bulletin G-1, illustrating and describing the four conveying systems built by Fuller.

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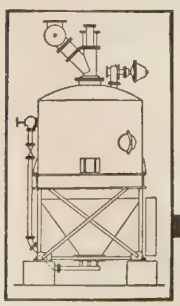
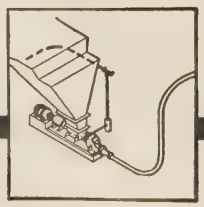
Branch offices

Chicago—San Francisco—Los Angeles—Seattle—Birmingham

FULLER-FLUXO



FULLER-KINYON



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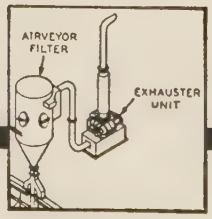

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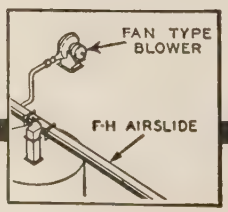

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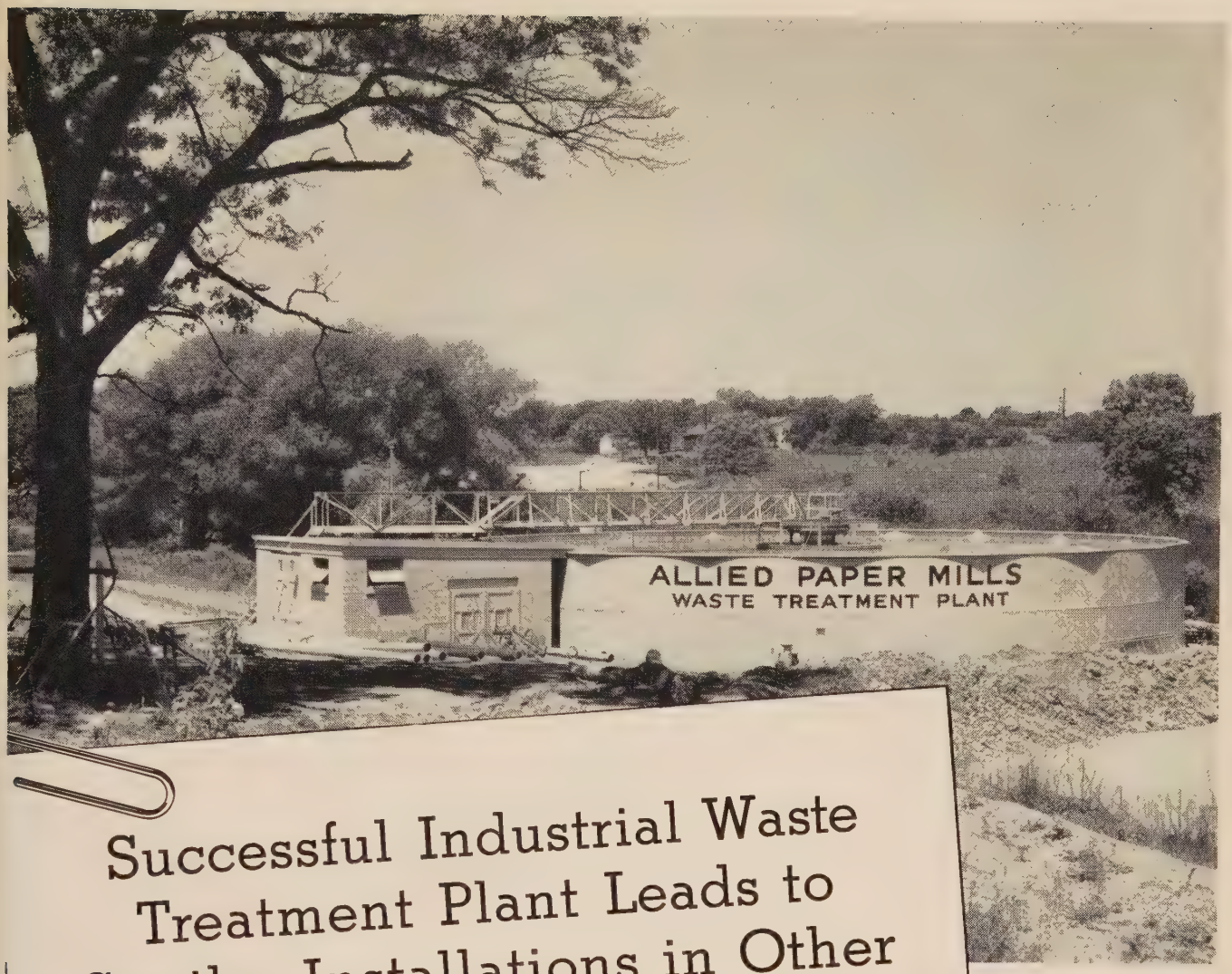

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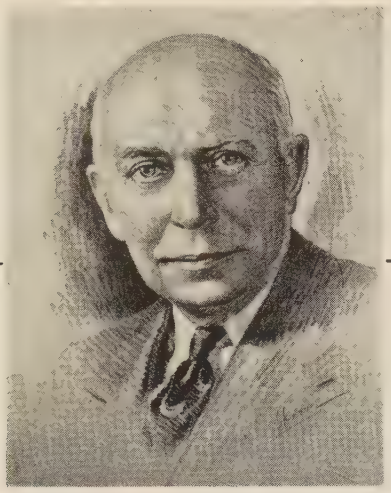
THE OUTLOOK FOR WOOD PULP

D. C. EVEREST



D. C. Everest

For more than 35 years I have been doing in my own way what I have been requested to do here; that is, to appraise the business outlook in the chemical pulp industry and the paper and paperboard industry as it exists today, and to give you my ideas as to how the short and long range possibilities for profit will develop.

My first assumption is that we are all in business to make as large a financial return as possible on the capital invested in our respective concerns, tempered, of course, by due recognition of the interests of our customers and by our desire to market our products price-wise so as to promote their optimum consumption. If there are those who engage in the pulp, paper, and paperboard manufacturing business merely for the fun of it or for some eleemosynary purpose, I have failed to find such people after nearly 55 years' association with those industries. I have heard some of my friends in the industry say, after the delivery of one of my "guesstimates" on the short and long range outlook, that I was merely "playing the same old record." I have also acquired the sobriquet of the "perennial optimist." I would like to say here that after this rather long experience in the industry, I have only been optimistic when, in my opinion, conditions warranted such a viewpoint.

Anyone who maintains an optimistic outlook at all times regardless of conditions, and I may say that conditions change more rapidly today than they did even a few years ago, is simply a "Pollyanna." If an industry or a segment of an industry is to be successful, the people who are engaged in it cannot be floating around in the clouds or picking daisies. They cannot take over-all industrial indexes as a guide to their own most remunerative future action. This is an era of analysis, and a mighty careful analysis coupled with all the imagination and preception one can muster, if he is to consider an expansion program or a revamping of old facilities.

Pretty much all of the decisions made are based on over-all statistics which are available to everyone engaged in the industry. If indications are that an expansion of "X" tons is warranted, it might be done by one concern and the industry not feel any effect profitwise from such expansion. We do not do it that way, however, and instead of one concern increasing its productive capacity, we may find ten different concerns doing the same thing.

About the only thing which will deter anyone from increasing productive capacity at this time seems to be a lack of money. Money seems, at the moment, in good supply and can be gotten either through the sale of common stock equities, preferred stocks (particularly those with a conversion into common stock feature attached), bonds, debentures, or notes in some form at relatively low rates to cover the needed funds.

With all that is going on in the various research departments of government and private industrial laboratories today, I am a bit confused as to the type of pulp mill I would build at this time or the species of wood with which I would endeavor to supply it. It would be difficult to determine whether it would operate on soft or hardwoods or a percentage of each. What would look like an ideal plan at this time may be obsolete before the mill is completed. Location and many other features including wood supply may be extremely important in a long range appraisal of any new development.

Let us examine the situation on an over-all basis as it appears today.

As we approach the end of the greatest expansion cycle in the long history of the pulp and paper industry, it is an appropriate time to look at the record and consider the outlook.

The domestic wood pulp industry has tripled its productive capacity in the past 20 years. Since the end of World War II, pulp capacity in the United States has increased at an average rate of a million tons a year—from 12 to about 22 million tons. About half of this 10 million ton capacity increase is in 32 new mills built since 1946; the other half has resulted from improvements and additions to existing facilities.

Ten million tons of new postwar capacity represents a lot of pulp. It is, for example, more pulp than Canada has ever produced in any single calendar year. It is more pulp, by almost 50%, than the entire Scandinavian industry produced in its best postwar year. And it is more pulp, by 52%, than the United States produced in its most favorable prewar year.

We used to be concerned about the impact of pulp imports from Europe upon our domestic economy—and quite properly so. In their peak year, however, imports from Europe totaled less than $1^3/_4$ million tons—only about one sixth of the new domestic capacity installed since the end of World War II. This arith-

D. C. Everest, Chairman of the Board, Marathon Corp., Rothschild, Wis.

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metic may help to place in proper perspective the significance of this postwar growth.

The last of the major expansion projects now pending are scheduled for completion this Fall. There have been no "new starts" for many months. In the absence of scheduled "new starts," the next 2 years are bound to witness a sharp decline in the domestic industry's recent rate of growth.

This hiatus in physical growth will afford domestic pulp and paper producers an opportunity to review their current position, consolidate their gains, and give more studied attention to their future.

EFFECTS OF EXPANSION

An expansion cycle of the magnitude of the one that we have just been through, obviously, has solved many problems for many people.

In combination with an expansion of somewhat lesser magnitude in Canada, it has, for the time being, eliminated fear of pulp and paper shortages in North America. It has reduced United States' dependence upon overseas' fiber supply sources. It has guaranteed long range continental self-sufficiency in fiber and fiber products. It has resulted in greater product diversification. It has furthered our national security by solving problems of those concerned with matters of national defense. In these respects, expansion has accomplished what it was intended to accomplish.

But expansion also creates problems: technical, economic, and social. Increased production will result in increased requirements of wood, water, power, and chemicals; individually and collectively, we must devote more attention to the short and long range problems incident to raw material procurement. Expansion will also increase our personnel requirements both at the operating and executive level, and force us to pay more attention to problems of recruitment, training, and employee relations.

It will result in bigger and better pollution problems that will cry for intelligent solution in the public interest. It will result in more aggressive competition, and necessitate a better understanding of market behavior and of the arithmetic of "break-even" costs. it will necessitate more intensive study of the possibility of further end-product and by-product development. And it will require more careful market research to insure that any new expansion is realistically geared to prospective requirements for the future, and not blindly geared to the growth rate of the recent past.

To the consideration of this last problem, I'd like to contribute a few thoughts.

THE GROWTH RATE

Two factors determine the rate of growth for wood pulp: (1) the growth rate for the end products of fiber, and (2) the relative importance of wood pulp in the over-all fiber furnish of these end products.

Let's examine these factors as they have operated in our pulp and paper economy in the recent past, and as they may be expected to operate in the period ahead.

End-Product Requirements

In the postwar period (1945–53), domestic consumption of paper and paperboard has increased 11.5 million tons or 59%. Of this total increase, only one fourth was attributable to increased population; the remaining three fourths was attributable to increased per capita consumption. If, since 1946, we had depended upon population increases alone to generate new markets, our paper and board consumption last year, instead of totaling 31.25 million tons, would have totaled only 22.4 million tons.

Looking ahead, human nature being what it is, we can probably continue to count upon a reasonably constant increase in population; this factor alone will justify a limited expansion of the market for most of our end products. To justify continuance of the expansion rate to which we have become accustomed, however, we must maintain the historical rate of increase in the major component of growth, namely, per capita consumption. This will not be easy for this historical rate of growth has been high. It has been high for two reasons: (1) because the industry has been able to develop an ever-widening range of end products designed to meet consumer needs, and (2) because the over-all economic and political climate has been such that the consumer can afford to buy these products in ever-increasing volumes.

The Over-all Economic Climate

As to the basic soundness of our American economy and the ability of the American consumer to continue buying our products in ever-increasing volume, I am still the "perennial optimist" that some of you have labeled me. We have not abolished the business cycle, but we have learned more in this country about the control of cyclical fluctuations. Basic readjustments in our over-all economy have been completed during 1954 with little or no loss in disposable personal income or consumption expenditures, and little or no change in savings or the investment potential represented by savings. Historical precedent to the contrary, I believe that, with *competent economic and political leadership*, we can keep our over-all national economy strong and healthy and continue to avoid serious depression and large scale unemployment in the future. With adequate natural resources and adequate productive facilities, there is no sound reason why our problems of distribution cannot be solved, and the "boom or bust" pattern put to rest. I look for continued long term improvement in this country's productivity and its basic living standards.

At the same time, however, we should bear in mind that some of the economic and political factors that have contributed to our per capita growth in recent years may not be operative in the future or, if operative may be less potent in their impact upon future paper requirements. The accumulated unsatisfied demands of the war period, for example, have long since been fully met, and there is no longer a lag in our long-term rate of growth attributable to a deferment of normal expansion during the war.

Further, our recent expansion has already taken into account the needs of national defense in the event of a new national emergency; the preparedness program recommended by the defense authorities is about completed, and the need for new facilities for defense will be relatively minor consideration in considering the

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justification for further expansion. Similarly, in our forward planning, we can perhaps assume that foreign aid, economic assistance programs, and federal government expenditures will generate a relatively lower paper and paperboard requirement in the future than they have in the past.

If the rate of growth in per capita consumption is to be maintained, other incentives must be found to replace incentives that may have reached the point of diminishing return.

Market Development

While I am generally optimistic as regards the forward trend of our over-all national economy, my optimism in respect to the ability of the paper industry to generate consumer demand for its products as effectively in the future as it has in the past is more restrained. In the absence of more tangible evidence of constructive new market development in this country, excessive optimism in respect to the prospective growth rate for domestic paper consumption does not appear to be justified.

The high rate of growth in per capita consumption of paper during recent years has, for the most part, been a result of *ideas* born in sweat and blood during the worst economic depression in the nation's history. The existing green pastures of the paper industry, at that time, were relatively few, and never more unfertile. Market development was a matter of the starkest economic necessity. New pastures had to be invaded, and old ones cultivated to support life in the industry.

The largest pastures selected for invasion were in the fields of packaging and building. Paper succeeded in gaining a foothold in these fields because it was found that it could supply serviceable products for these markets at less cost than competing industries. The same poverty that created the famine, with a little nudging, created the demand for new paper products that were less expensive than other products serving the same markets.

The growth in per capita consumption in the past 20 years has been attributable in large measure to the successful exploitation of these basic marketing ideas. Improvements in quality, over the years, have enabled us to establish a beachhead and consolidate our gains in these major markets. Today, over half of our total paper and board consumption is used for packaging purposes. The building industries have become the outlet for an increasing share of our total paper supply.

Whether we can continue to maintain the spectacular growth rates of the past in these important segments of the economy is open to some question. The *obvious* potential markets for packaging and building materials have been pretty thoroughly exploited. In these particular fields, our market research in the future must be directed to the less obvious. Further, as the quality of our products has improved and as competition for basic wood supply has increased, our costs have gone up. While we still enjoy a competitive advantage in these markets, both from the standpoint of relative cost and relative serviceability, the margin of our competitive advantage is perhaps shrinking. Increased competition from without the industry is inevitable, and the future of our growth rate in these segments of the industry will depend in part upon how successfully we meet this new challenge.

Sanitary products for household and industrial consumption have also contributed significantly to the recent increase in per capita paper consumption in this country. Consumption of sanitary grades, due in part to *new* product development, has tripled since 1937. World War II, with its attendant labor shortages, provided the chief incentive for this spectacular market development. Here, too, the ground gained is rapidly being consolidated. There may well be practical limits to our ability to find new applications of a sound basic idea that has already been well exploited. Fresh ideas and new products will be needed to keep the growth rate as dynamic in the future as it has been in the recent past.

Too rigid reliance upon historical *patterns* of growth has perhaps in the past been a common fault of those who have built the productive capacity of this industry. The tendency has been to examine growth trends in the industry and to build new capacity for the manufacture of those products for which the historical growth rate appears to have been highest. Sometimes this is like reasoning that just because Babe Ruth hit 60 home runs at age 30, he should have been able to hit twice as many at age 60. Everyone wants to join the high man on the growth rate totem pole—few pay much attention to the low man. Carried to extremes, such a policy can be disastrous. It could even knock over the whole totem pole.

There are opportunities for intelligent market development in *every* segment of this industry—not just in those segments that have come to be regarded as Cinderella's. Our market research programs must encompass the whole front, not just segments of it, and our future plant must be built with due regard for the whole pattern of growth of consumptive requirements. Otherwise, we may wind up with plant facilities that are lopsided in relationship to the new pattern of requirements. Within limits our errors of judgment can be corrected later by grade shifting, but we can save ourselves this needless expense if we plan wisely in the first instance.

By this, I do not mean to imply that market research should not be selective. Obviously, it must be. No one will knowingly spend time and money, for example, to measure the potentialities of markets that can probably never, under any circumstances, be won. It would be easy enough to measure the potential market for paper collars—by counting necks and determining standards of personal cleanliness. But what's the point? Who wants paper collars? The approach to market research must be both selective and rational. It must be based upon realistic appraisal of consumer habits and consumer needs, not as of yesterday, but as of tomorrow.

In our forward planning, of course, the possibilities of further market development abroad will not be overlooked. We know that, outside of North America, average per capita consumption of pulp and paper, despite spectacular improvement in recent months, is still less than it was prewar. For this reason, the potentialities of growth are relatively greater abroad than they are at home. We know, too, that improvements in the pulp and paper economies of the Old

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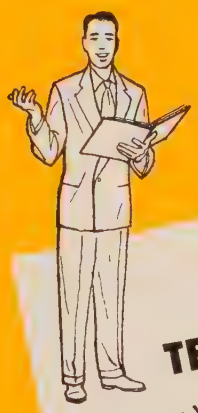

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World, for some years, must be based upon either North American fiber or North American end products. Beyond this, however, we know little about the basic factors that will affect forward trends in the pulp and paper economies of the Old World.

More extensive market research abroad, a better understanding of trends in those industries that consume pulp or paper abroad, and a more intensive study of trade and currency problems are prerequisites for intelligent export development. Foreign markets undoubtedly will absorb more of our products in the future than they have in the past. The important question, however, is how much more. Expansion of domestic facilities to supply export markets will necessarily be a more speculative venture than expansion to supply domestic needs. To the extent that we can learn more about the potentialities of these export markets, the element of risk in this type of expansion may be significantly reduced.

PATTERNS OF FIBER CONSUMPTION

The second factor that has accounted for the very high rate of fiber consumption in the domestic paper and board industry has been the rapid rise in the relative importance of wood pulp in the over-all fiber furnish of paper and paperboard.

In 1946, at the beginning of the postwar expansion cycle, 58% of our total fiber consumption in paper and paperboard was wood pulp; last year 65.6% of the total furnish was wood pulp. This is not surprising in view of the marked trend toward integration in paper and paperboard production.

What is significant, however, is the fact that if furnish ratios had stayed where they were in 1946, we would be consuming 2,172,000 tons *less* wood pulp than we are currently using. In other words, one third of the postwar growth in pulp consumption by the paper and board industry has been attributable to furnish changes; only two thirds of the total increase has resulted from growth in paper and paperboard production and new uses.

The installation of new integrated pulp and paper capacity, in addition to increasing the supply of paper made from virgin wood pulp, also operates to increase the potential supply of salvageable waste paper. In 1946, we recovered in the form of waste paper 32.3% of the total domestic supply of paper and paperboard; by the first half of this year, our salvage rate had dropped to 26.2%. Expressed differently, waste paper consumption in 1946 was equal to 60% of wood pulp consumption. The addition of 10 million tons of wood pulp capacity during the postwar period, on this basis, indicates a potential addition to the waste paper supply of 6 million tons. The actual increase in waste paper consumption between 1946 and 1953 was only 1.25 million tons. The unused increment in the waste paper potential would accordingly appear to be of a magnitude of 4.75 million tons, or four fifths of the total potential generated by the recent expansion of the wood pulp industry.

The point of all this is that the availability of this ncreased potential supply of waste is a factor that must be taken into consideration in considering future expansion of our pulp and paper facilities. As the supply of recoverable waste increases in relation to the demand, an ancillary expansion cycle could at some point begin in those segments of the industry that depend upon waste paper and market pulp.

Relative economics will, of course, determine the pattern of fiber consumption upon which the paper and paperboard industry's long range growth will be based. My own views are that, to the extent that waste from paper and paperboard made from improved quality of pulp is economically recoverable, it will gradually find a use and that the relatively more favorable increase in the use of wood pulp vis-a-vis waste will not continue for long at the postwar rate. If, in fact, we are to use relatively more waste in the over-all furnish of paper and paperboard in the future, we must make certain that, in our forward planning, we do not construct duplicate sets of facilities, one based primarily on virgin fiber and the other primarily upon waste, to serve the same end markets. To the extent that we do, we are inviting trouble.

I would like to make one observation as to potential waste paper supply in the short range period and that is I think too few of us realize how much waste paper is being made nonusable through coatings and additives of various kinds in the original furnish of the paper and paperboard. Until our research departments find out how to make this usable, users of waste papers and the waste paper dealers may have some severe headaches.

To show you how these things change and may outrun one's most optimistic viewpoint, I would like to quote from a talk I made in Chicago in 1945. I then dealt with the use of paper and paperboard in relation to national income and my old formula of a million tons of paper and paperboard consumption per 10 billion dollars of national income has been all upset in this 9 year period. My optimistic appraisal was very much underestimated. In concluding that talk, however, I did say some things which have more than come true. I did say:

"It is my thought that there will be many upsets in grades and uses postwar. During the last 5 years through the efforts of the technical staffs, there have been many new developments in grades and processes. Many of these new products have not been available for civilian use. When these are available, there will be many substitutions of these new products for those in the old established lines. I believe that the use of waste paper both in paper and paperboard will decrease from the high peaks of consumption we have known over recent years. Kraft board, for instance, will make further inroads on jute board. Folding and setup box grades will probably be changed requiring more virgin pulp and less waste paper.

"With the advent of more bleached sulphate pulp in the south and mid-south, I visualize a gradual regional shift in the manufacture of book, no. 4 bond, tablet, envelope, and similar papers. Machine coated book will play a very important part and with bleached sulphate pulps and bleached grownwood available, the filled book paper manufacturers may have a rough time. I do not look for any material increase in sulphite paper either in bleached or unbleached. The cost of wood which can be utilized in making bleached and unbleached sulphate papers will be the deciding factor.

"During the next 10 years I believe we will see a greater shifting of grades than in any previous 10 year

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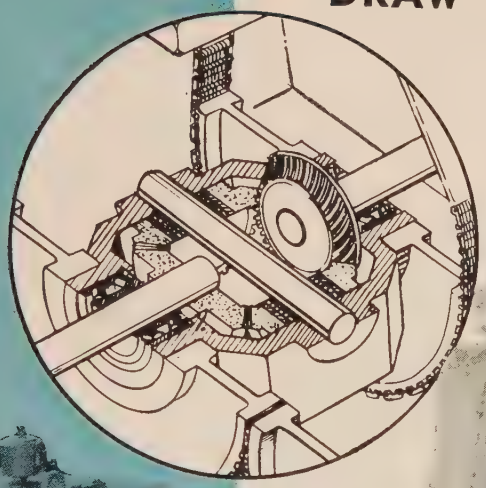

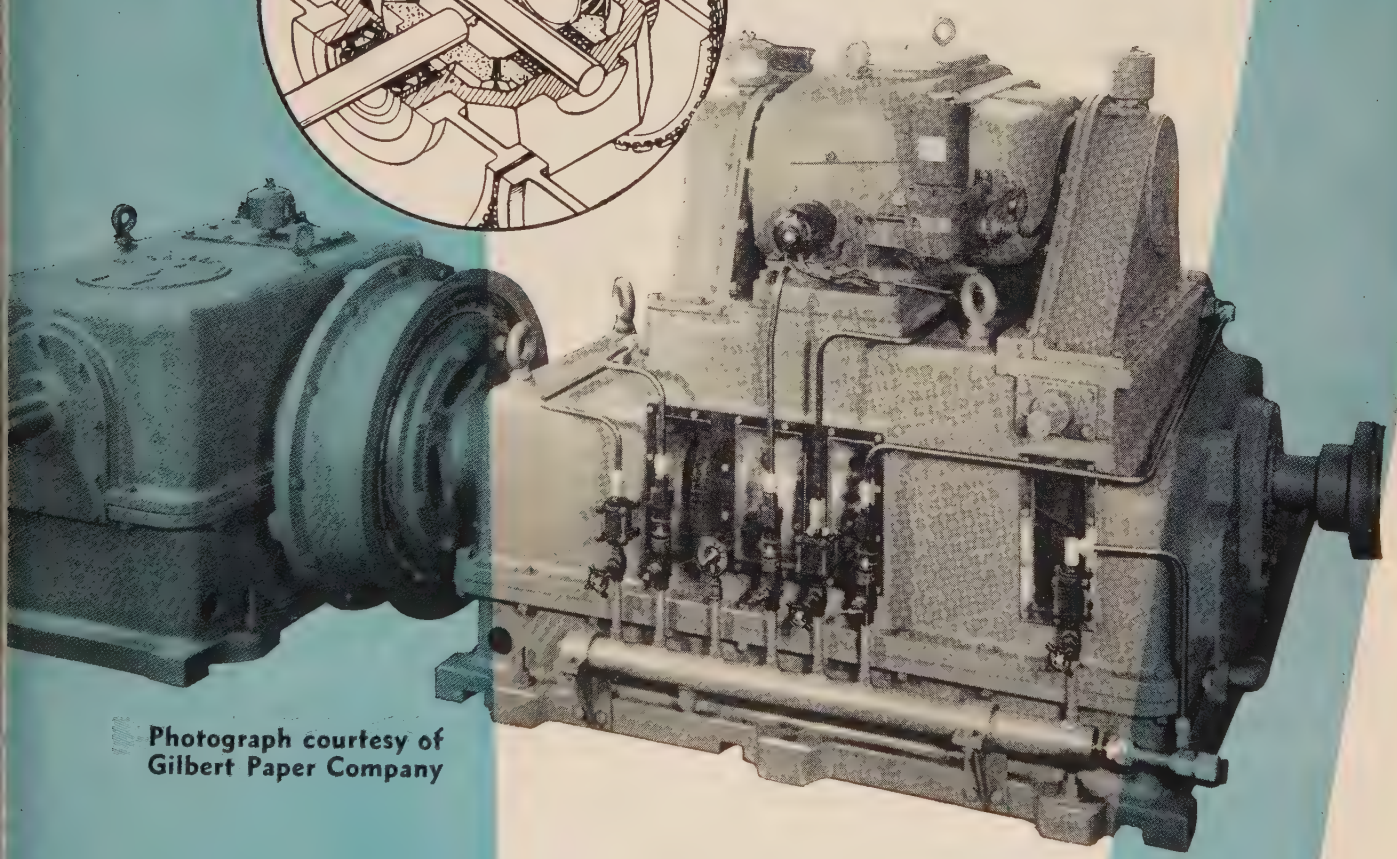

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period. Following the last war we went through a 10 year shift period which was largely caused by increased production of unbleached kraft. The 1930–40 period saw further increases in kraft paper and board and was the lush period for converters in building up an extending the packaging field.

"Our war experience has brought about developments which will give us another period of readjustment. This will come in many fields but more particularly those in which bleached sulphate may be utilized.

"My guess is that, except for some grades such as newsprint and 100% rag content papers, our prewar grades will not be recognized 10 years hence. There will be many improvements in processes and in products. It will pay those of you who are engaged in the technical end, both in paper and in the materials which enter into paper manufacture, to keep up with the procession. Every laboratory and every technician in every laboratory is working continuously for product improvement.

"As to its effect on the industry, I am reminded of an old Arabian proverb which says: 'All mankind is divided into three classes—those that are immovable, those that are movable, and those that move.'

"While as I have indicated, I believe there will be a great demand for paper and paper products postwar, nevertheless the cream of this business will go to those who are in the third classification of the old proverb, 'those that move.' "

CONCLUSION

Ours is a complex industry and no phase of our activity is more important or more difficult than planning forward supply. To the extent that pulp and paper producers underestimate this country's forward requirements and fail to provide for future needs, our national economy will suffer; to the extent that they overestimate requirements, the economic position of the industry will suffer. The decisions of each of us, in the last analysis, must be based upon our own best judgments, but in formulation of these judgments we must be everlastingly conscious of the basic forces at work in this industry and of the factors, economic, social, and technical, that could influence our future.

I think we have taken good care of the national interest and will continue to do so, but for our own continued prosperity, anything we do in the future will require the best brains we can assemble in the individual analysis and planning of our expansion programs and every other feature affecting our business enterprises.

In the analysis and planning for the future, we must be mighty careful in separating what we term the "short and long range" effect on our individual concerns and the industry as a whole. One can get awfully tired waiting for a "long range" effect to develop. We will all have to be sure of our ground before taking action, particularly when we know we are all faced with as confusing a world situation as we have ever experienced.

Presented at Fall Dinner Meeting of the United States Pulp Producers Assoc., Inc., Three Lakes, Wis., Oct. 7, 1954.

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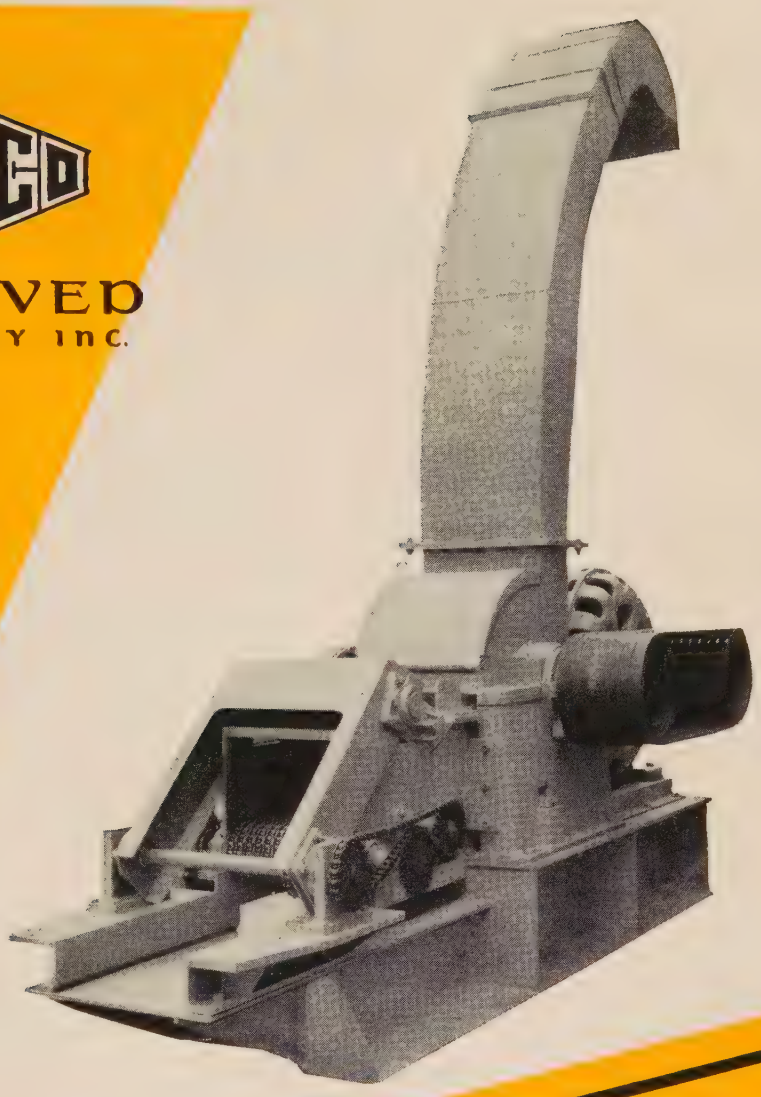

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THE CONTRIBUTION THAT SUGARCANE BAGASSE CAN MAKE TO THE PAPER AND BOARD INDUSTRIES

ELBERT C. LATHROP and SAMUEL I. ARONOVSKY

SUGARCANE bagasse as a raw material has attracted the paper industry for a long time because of its annual availability in large quantities as a by-product. Hundreds of technical reports and patents relating to conversion of bagasse into pulp, papers, and boards are available for review. No industrial success and, indeed, numerous industrial failures resulted from this work until 33 years ago at which time the manufacture of insulating building materials from bagasse was started and proved successful. However, successful manufacture of paper from bagasse did not take place for about another 18 years. Now, at least 10 plants are producing paper or board products from bagasse which are industrially acceptable in the respective countries in which they are being manufactured (*1*). With perhaps no exceptions, the papers so made would not meet industrial standards in the United States.

Economic and technological factors have been responsible both for the failures of the past and for the differences in the quality of the products now being made. At present there are very great differences in economic conditions between countries and between the competitive situations within countries. As competition becomes more intense, quality of product plays an increasingly important role in industrial survival until, under the most severe conditions, that product which has superior inherent properties outperforms and takes first rank.

Much has appeared of late in the daily and technical press about new processes for pulping bagasse, new mills to be built, and particularly about making newsprint from bagasse alone. These stories have been written for many purposes: political, promotional, and technical. Most of the reports have, of course, some basis in fact, but the bias with which some were written and the unqualified character of many of the statements have proved very confusing. On the one hand, a person might be led to believe that bagasse is ideally suited to make almost any kind of paper, and on the other that its utility is quite limited. Neither opinion would be correct.

It is the purpose of this paper to present factual information concerning the kinds of pulps and papers, from the poorest to the best, that our present knowledge tells us may be made from bagasse. The various pulping methods that may be used, based on industrial experience, will be described briefly. Chemical requirements, yields, and the general qualities of pulps produced by the several methods will be discussed. It is hoped that information of this type will be useful in arriving at decisions that will lead to commercial successes in using bagasse in the paper and board industries.

In recent years renewed interest in the use of annual plants for papermaking has resulted in extensive research by pulp and paper laboratories of a number of governments. The published researches of these institutions have cleared away many earlier misconceptions and form the basis of a rational technology. Our knowledge of pulping methods and of the pulps and papers that may be made from annual plants now compares rather favorably with that of wood and is indeed advanced over that of tropical woods. It has been shown that rational methods for pulping specific annual plants must be based on a knowledge of their physical and chemical characteristics so that pulping chemicals and conditions may be properly designed. In general, pulps made from annual plants do not have the same properties as those made from pulpwoods and cannot be expected to behave exactly alike on the paper machine or to make identical papers. In some cases these pulps will make papers or boards superior to those made from wood pulps, in other cases their best use is in blends with wood pulps. Often in the latter use, papers superior to those made wholly from wood pulps may be produced.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF BAGASSE

The characteristics of the fibrous elements of the cane stalk as it enters the sugar mill are described as follows: the outside of the stalk (rind) comprises a relatively tough ring. The inside consists of soft medullary tissue in the cells where the sugar is deposited. Lengthwise through this tissue run numerous fibrovascular bundles of various sizes so placed that the smallest are packed near the outside and the larger ones, less abundant, are distributed toward the center. The rind is formed of thick-walled, elongated cells of hard or sclerenchymatous fibers. The fibrovascular bundles comprise groups of fibers and ducts. The pith, or parenchymatous cells, are short, broad, and of low resistance to penetration. These cells group around and adhere both to the fibrovascular bundles and the rind fibers. The outside of the rind often appears glassy, carries a coating of wax, and may be of a number of colors. At intervals in the length of the stalk, which vary in accordance with conditions of growth of the cane, the fibrovascular bundles send branches outwards, thereby forming a portion of dense tissue called the node. Neither the pith nor perhaps the tissue concentrated in the node is suitable for papermaking (*2*). Fibers from cane leaves are also of little or no value in paper or board manufacture since they are so short that most are destroyed or lost during pulping and washing operations. Generally leaves and trash are removed from the cane in the field, but when mechanical harvesting of the cane is practiced the bagasse will contain more or less trash and leaves.

Table I. Physical Composition of Various Varieties of Sugarcane

Basis percentage of dry matter

Constituent	Louisiana purple, %	Java Cheribón, %	Java No. 36, %	Java No. 100, %	Java No. 139, %	Java No. 247, %
Pith	24.6	25.6	20.0	22.8	20.0	20.0
Bundles	18.6	31.5	26.5	25.4	36.0	26.1
Rind	56.7	42.9	53.5	51.8	44.0	53.9

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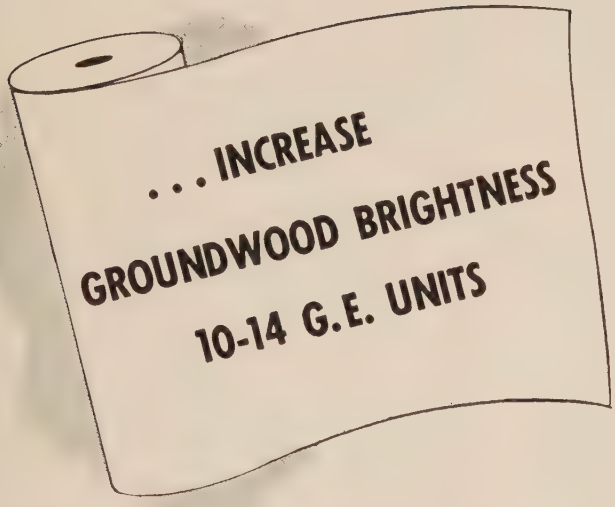

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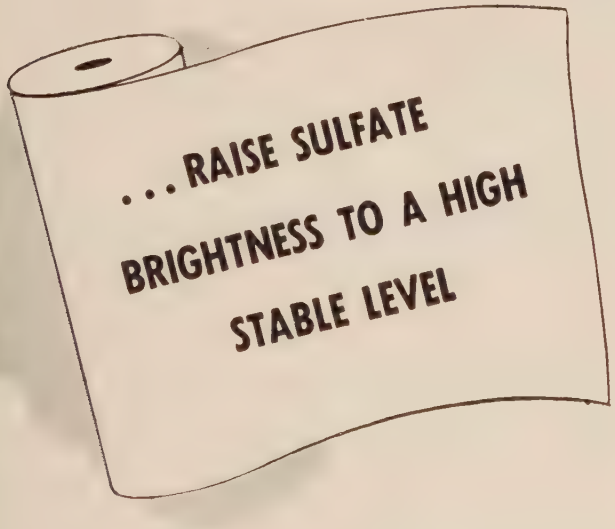

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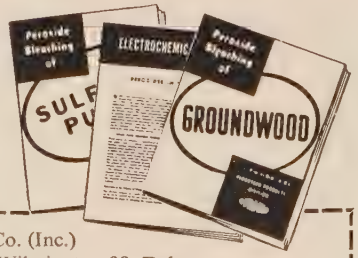

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Table II. Variations in True Fiber and Pith Content of Certain Varieties of Florida Sugarcane

Percentage based on dry bagasse free from dirt and solubles

Cane variety	*Fiber, %*	*Pith, %*	*Fiber/Pith Ratio*
F. 31-436	69.6	30.4	2.289
P.O.J. 2725	65.4	34.6	1.890
Cl. 38-32	78.1	21.9	3.566

[a] Private communication from B. A. Bourne, United States Sugar Corp., Clewiston, Fla., Oct., 1953.

It will be noted that cane is composed of three rather different elements, e.g., pith, fibrovascular bundles, and bundles of rind fibers. Browne (*3*) made a careful analysis of the percentage of these elements in several varieties of cane, the results of which are given in Table I. The proportion of these elements will vary depending on a number of factors, chiefly the variety of cane. The variation in pith and fiber content of three varieties of cane grown in Florida is given in Table II. Bagasse also contains a variable amount of soil and dirt, depending on the soil character and on the method of harvesting. If the leaves are burned in the field, the cane will carry many carbon particles. The proximate physical composition of five different samples of commercial bagasse from widely separate locations is given in Table III.

The moisture content of the bagasse from the cane mill may vary from 41 to 51%, and often runs about 48%. Sucrose remaining in the bagasse varies, depending on the conditions, from 2 to 5%. Keller (*4*) states that the color of bagasse will vary from a grayish-white to a very dark green. The material is nonhomogeneous in size, varying from a dust that will pass a 60-mesh screen to particles around 6 in. long by $^3/_8$ in. in cross section. Usually about 97% will pass a 1-in. square opening. The analysis on an "as-produced" basis is about the following:

	Per cent
Moisture	49
Fiber and dirt	45
Soluble solids	6

The proximate chemical composition of samples of bagasse representative of different varieties and from different countries is given in Table IV. The sample of Louisiana bagasse is representative of commercially stored bagasse; the remainder of the samples were dried immediately from the sugar mill.

For comparison the proximate chemical composition of certain pulpwoods is given in Table V. The fiber dimensions of sugarcane, some cereal straws, and certain pulpwoods are given in Table VI.

PAPERMAKING POSSIBILITIES OF BAGASSE AS INDICATED BY PHYSICAL AND CHEMICAL PROPERTIES

Knowledge of the relationships between the physical and chemical composition of fibrous raw materials, or of their ultimate fibers, and their utility in papermaking has become extensive. An analysis of the data presented above leads to the following conclusions:

The composition of bagasse is variable, depending on variety, soil, method of harvesting, milling, and other factors. All bagasse contains dirt and if the leaves are burned in the field, it is likely to contain carbon particles. In any case, dirt and carbon are undesirable in papermaking. While a certain amount of these impurities can be tolerated in board manufacture, their presence in pulps used for high-grade papers, or those intended for bleaching, will result in extra expense for chemicals, lower yields, and pulps of poorer physical properties.

Bagasse is composed of three elements, to which must be added short leaf fibers if much leaf enters the mill with the cane. Two of these elements are fibrous: namely, the fibrovascular bundles and the rind fibers. The third element is parenchymatous tissue, or pith, a material not fibrous but composed of soft, rather unorganized tissue. The surface area of pith is vastly greater than that of an equal weight of the fibrous elements. The ratio of the three elements to each other will depend on several factors, chiefly variety of cane.

The chemical composition of different samples of bagasse varies somewhat, but this variation is less than that found in physical composition, i.e., rind, fibrovascular bundles, and pith. Canes that are more mature when harvested will have higher lignin content. Evidence accumulated in studying the chemical composition of annual plants shows that the relationship between the lignin, cellulose, and pentosan contents of straws, stalks, and cobs may be altered by plant breeding. A comparison of the chemical composition of the respective samples of pith and fiber obtained from whole bagasse samples shows that the pith contains more ash, pentosans, and 1% NaOH solubles, and less cellulose than the fiber. The greater ash content is due to the greater surface area of the pith which absorbs more dirt.

The percentage of hot-water-soluble material is greater in the whole bagasse samples than in either the fiber or pith separated from them. This is due to the fact that separation of pith and fiber was carried out by a wet process. It will be noted that the hot-water-soluble material is lower in the stored bagasse than in the other samples. During the storage period the sugars present in the fresh bagasse are destroyed by fermentation processes.

Compared with the chemical composition of the pulpwoods, shown in Table V, fiber separated from bagasse is lower in lignin content in most cases than either the softwoods or hardwoods and contains more pentosans and more material soluble in 1% NaOH. Bagasse fiber compares rather favorably with the pulpwoods in cellulose content. In chemical composition, bagasse more closely approximates the hardwoods than the softwoods and, therefore, its papermaking properties more closely resemble those of the hardwoods.

Comparisons with Wood Pulps

Bagasse is easier to pulp than the hardwoods and requires less chemicals for pulping. This is due to the greater ease of penetration of chemicals into the fibrous elements of the bagasse as compared with the dense chips of the pulpwood and also to the lower lignin content of the bagasse.

Normally, pulps made from hardwoods or from stalks and straws contain more pentosans than softwood pulps. In general, pulps which contain higher concentrations of pentosans,

Table III. Proximate Physical Analysis of Various Samples of Whole Bagasse. Results Reported on Original Bagasse Oven-Dry Basis

Type of whole bagasse	*Florida variety F. 31-962 (1952), %*	*Florida variety Cl. 41-223 (1952), %*	*Louisiana Thibodaux stored (1952), %*	*Hawaiian variety 8560 (1952), %*	*Puerto Rico Aguirre (1951–52), %*	*Philippine Islands Negros (1952), %*
Fiber	58.0	60.7	64.4	60.5	60.1	68.6
Pith	22.8	24.3	25.2	32.9	25.5	23.8
Solubles, dirt, and loss	19.2	15.0	10.4	6.6	14.4	7.6

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up to a certain maximum, have been found to beat faster and to develop greater strength than corresponding pulps containing less pentosans. On the other hand, pulps containing high percentages of pentosans tend to make denser and harder surfaced papers with lower opacity than those produced from softwood pulps. In the manufacture of glassine papers and corrugating medium, high-pentosan-containing pulps are a necessity. The use of high-pentosan pulps as blends with other pulps, particularly groundwood or weaker pulps, produces improved paper products. Using prehydrolysis treatments it is possible to prepare pulps from bagasse, straws, and hardwoods that are lower in pentosan content and which, therefore, produce less dense, more opaque, and softer papers. These treatments lower pulp yields and increase costs.

A direct relationship exists between the dimensions of fibers and their papermaking properties. Tear resistance is associated with fiber length; short-fibered pulps are deficient in this property. Since strength in papers is attributed to the bonding of individual fibers, it follows that fibers with a high ratio of length-to-diameter will, other things being equal, con-

Table IV. Proximate Analysis of Various Types of Bagasse

All values except moisture on oven-dry basis

NURB no.	Material	Moisture, %	Ash, %	Lignin, %	Pentosans,[a] %	Extractives in, %			Cross and Bevan cellulose, %				
									C and B cellulose		Alpha as run		Alpha-basis original
						Hot water	Alcohol benzene	1% NaOH	Ash free	Pentosans in	Ash free	Pentosans in	ash and pentosan free
1267	Louisiana whole bagasse, stored (Lockport, 1941)	4.1	2.9	21.3	29.4	4.0	1.7	32.9	58.4	29.3	67.2	6.1	36.8
1267	Louisiana bagasse fiber, stored (Lockport, 1941)	6.8	2.0	20.7	30.0	2.4	1.6	28.4	61.4	31.7	70.0	10.0	38.7
1267	Louisiana bagasse pith, stored (Lockport, 1941)	12.2	4.6	21.3	29.9	3.1	1.7	36.1	54.6	30.3	62.8	5.7	32.3
1740	Louisiana whole bagasse, fresh (Houma, 1941)	4.9	2.4	18.9	30.0	8.8	6.0	35.9	53.3	27.9	67.3	7.0	33.4
1740	Louisiana bagasse fiber, fresh (Houma, 1941)	9.7	2.2	19.9	32.5	3.4	2.0	30.5	59.0	29.6	67.7	8.1	36.7
1740	Louisiana bagasse pith, fresh (Houma, 1941)	8.7	6.3	18.0	30.7	3.4	2.9	36.2	52.5	28.7	62.4	6.6	30.6
7892	Florida whole bagasse, fresh, dry screened (Clewiston, 1948)	7.3	2.2	18.1	27.9	11.2	10.8	39.9	52.0	26.9	68.0	4.7	33.7
7892	Florida bagasse fiber, fresh (Clewiston, 1948)	7.2	2.0	19.1	30.9	4.5	2.6	31.2	60.4	29.0	67.2	4.5	38.8
7892	Florida bagasse pith, fresh (Clewiston, 1948)	8.9	3.4	18.2	31.4	4.6	2.5	35.0	53.9	26.2	63.4	4.0	32.8
9940	Florida whole bagasse, variety Cl. 41-223 (Clewiston, 1952)	8.6	1.0	18.2	26.6	15.1	7.0	40.7	48.0	28.1	66.9	4.7	30.6
9941	Florida whole bagasse, variety F. 31-436 (Clewiston, 1952)	10.1	1.6	16.4	27.4	15.5	6.4	43.2	48.8	32.7	66.5	5.3	30.8
9942	Florida whole bagasse, variety F. 31-962 (Clewiston, 1952)	10.5	2.2	18.6	28.7	9.8	8.0	40.0	49.0	26.5	67.7	5.2	31.5
9992	Hawaiian whole bagasse, variety 8560 (1952)	13.2	5.4	21.3	27.7	5.7	3.2	33.9	50.2	27.4	69.6	8.8	31.8
9992	Hawaiian bagasse fiber, variety 8560 (1952)	5.6	2.0	21.1	30.7	2.4	3.6	28.8	56.0	28.8	73.4	10.4	38.3
9992	Hawaiian bagasse pith, variety 8560 (1952)	7.1	3.3	20.0	33.0	1.5	2.1	30.8	53.5	29.7	62.7	6.7	31.5
9333	Hawaiian whole bagasse (Laupahoehoe Sugar Co.)	8.0	1.9	22.5	31.2	3.4	2.1	31.4	55.4	27.7	72.5	8.3	34.3
9573	Hawaiian whole bagasse, variety 1933 (Ewa Plantation)	7.7	2.6	19.3	31.3	4.0	3.6	31.3	55.0	33.4	62.6	8.2	31.6
9851	Hawaiian whole bagasse, variety 1933 (Oahu Sugar Co.)	7.9	3.3	20.1	31.0	2.7	3.4	32.0	52.0	32.4	65.7	7.4	31.7
10081	Puerto Rican whole bagasse (Aguirre 1951, 1952)	7.5	3.9	18.1	29.6	8.0	5.4	27.3	50.9	31.1	63.7	7.0	30.1
10081	Puerto Rican bagasse fiber (Aguirre 1951, 1952)	11.5	1.2	19.8	31.6	1.4	2.7	27.3	59.9	30.4	67.2	5.7	40.2
10081	Puerto Rican bagasse pith (Aguirre 1951, 1952)	4.9	3.2	18.8	31.9	2.8	2.9	30.3	53.9	30.3	60.4	6.4	32.6
10564	Mexican bagasse pith (San Cristobal, 1953)	6.2	4.9	22.4	29.9	7.6	2.3	40.1	46.0	25.5	61.3	5.5	26.6
10566	Philippine whole bagasse (Negros Island, 1952)	10.2	2.3	22.3	31.8	2.8	3.0	31.3	56.8	30.6	70.2	12.5	34.9
10566	Philippine bagasse fiber (Negros Island, 1952)	5.3	1.2	21.8	31.2	1.9	2.1	26.8	62.9	31.9	72.0	9.1	41.2
10566	Philippine bagasse pith (Negros Island, 1952)	3.3	2.6	22.5	33.2	3.6	2.7	36.2	55.4	32.2	66.8	5.7	34.9

[a] Pentosans = furfural × factor 0.8.
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Table V. Proximate Analysis of Some Pulpwoods in Percentage of Original Woods[a]

	Lignin	Pentosans	Extractives: Ether	Extractives: Hot water	Extractives: Alcohol benzene	Extractives: 1% NaOH	Cross and Bevan cellulose
White spruce	27.8	12.1	1.1	2.1	2.3	11.6	60.6
Jack pine	29.9	14.0	2.4	3.1	4.2	13.9	58.3
Aspen	23.4	22.1	1.1	3.3	1.3	20.4	64.6
Paper birch	26.8	26.5	1.0	2.1	3.2	17.3	60.4
Red gum	21.4	20.7	0.5	2.5	2.0	12.0	60.5

[a] "Pulp and Paper Manufacture," 1st ed., vol. 1, page 59, McGraw-Hill Book Co., 1950.

tribute greater strength than broader fibers of the same length. "Formation" in papers is associated with fiber length and with degree of fibrillation of the pulps used. Softwood pulps, having long fibers and often fibrillated by the considerable refining required, produce less well-formed papers than shorter fibered pulps from bagasse or hardwoods. In turn, the blending of bagasse or hardwood pulps with longer fibered pulps will produce papers of improved formation and better suited for printing.

Reference to Table VI shows that bagasse and the cereal straws are composed of a number of fibrous elements which differ considerably in dimensions. The rind fibers of the cane are longer than those of the vessel segments (fibrovascular bundles) and have narrower fiber diameters. The rind fibers will therefore produce stronger papers, particularly in respect to tear resistance. While the rind fibers are shorter than those of the softwoods, they are longer than those of the hardwoods and will produce more tear-resistant papers than the latter. Cane fibers have a length-to-diameter ratio practically the same as that for softwoods and considerably more favorable than that for hardwoods.

Pith a Major Problem

Reference has been made to the unorganized character of parenchymatous or pithy material. It will be observed from Table VI that the pith particles of the cane or of straws are very short and broad. Taking these facts into account it is easy to see that these particles can contribute little to papermaking unless they can be separated and especially treated to carry out special functions, such as fillers. There can be no mystery as to what happens to pith particles during the pulping and papermaking operations. Pulping operations are carried out in order to remove unwanted lignin and other impurities to the extent required for making particular papers or boards. The chemical reactions taking place in pulping are in all cases between the chemicals and the surfaces of the materials being pulped. The reactions therefore proceed faster on those particles having the greater surfaces. In the case of bagasse, this means that the chemicals act much more rapidly on pith than on rind or fibrovascular bundles, due first to the much larger surface of the pith and, second, to the greater ease of penetration of the chemical into it. In turn, the chemicals act more rapidly on the fibrovascular bundles than on the rind fibers, due to their greater surface area and to the fact that they contain ducts which make the penetration of the chemicals into them more rapid. These facts have been thoroughly demonstrated in present commercial practice.

Pith therefore uses up chemical more rapidly than the fibrous elements and is more quickly softened. Pulps are handled entirely in water suspensions; they must be pumped, dewatered over wire surfaces, and defibered or refined by attrition. All of these treatments contribute to loss of the unorganized pithy material from the pulps. On the other hand, because of their greater surface areas, the pith particles absorb more dirt, which only can be removed by destruction of the pith cells. They, therefore, make the bleaching of pulps much more difficult, requiring larger amounts of bleaching agent and resulting in weaker pulps and lower yields. Finally, the drainage rate of pulps has a direct bearing on character and rate of paper machine operation. Pulps containing pith will drain much more slowly than pulps made from bagasse fibers from which pith has been separated. Since prehydrolysis processes are also chemical, pith will react in these processes more rapidly and to a greater extent than fiber.

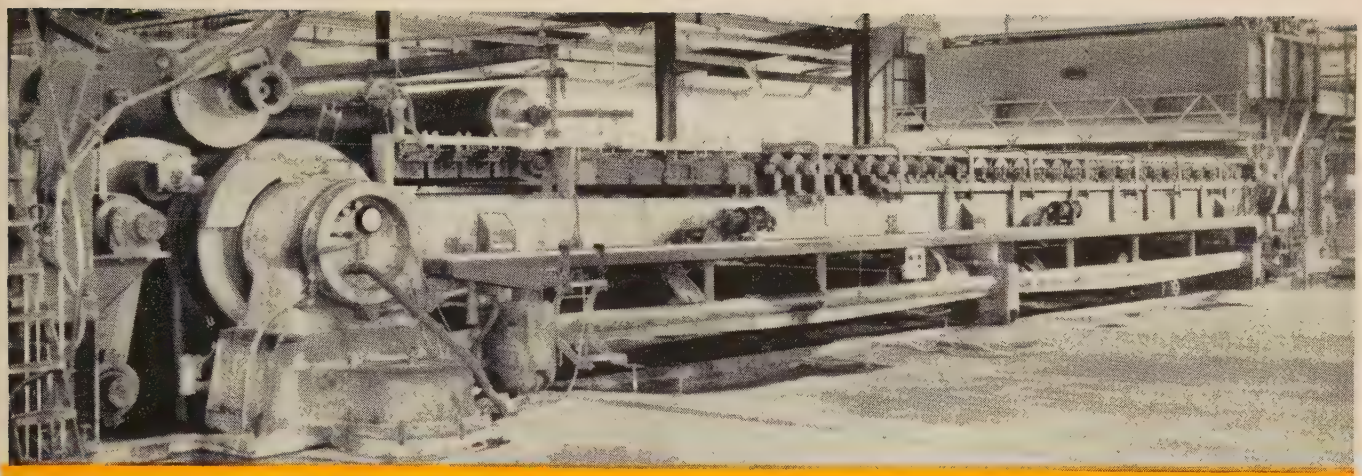
PROCESSES FOR PULPING BAGASSE

The most authoritative discussion of this subject will be found in FAO Forestry and Forest Products Study No. 6 (*5*). That report is the result of a thorough discussion of the subject and unanimous approval of recommendations by pulp and paper specialists called together in Rome, Dec. 3–14, 1952, by FAO. The report on bagasse drawn up by the group assigned to consider nonwoody fibers, of which the senior author was chairman, discusses in detail the processes recom-

Table VI. Fiber Dimensions of Bagasse, Straws, and Some Pulpwoods

	Length, mμ: Average	Length, mμ: Maximum	Length, mμ: Minimum	Diameter, mμ: Average	Diameter, mμ: Maximum	Diameter, mμ: Minimum	Ratio average length to diameter
Sugarcane[a]							
Fibers	1700	2800	800	20.0	34.1	10.2	85:1
Parenchyma	...	840	...	...	140.0	...	...
Vessel segments	...	1350	...	...	150.0	...	...
Wheat, rye, oat straws[a]							
Fibers	1480	3120	680	13.3	23.8	6.8	111:1
Fibers with thin walls	...	2900	800	...	34.0	...	...
Parenchyma	...	450	...	...	130.0	...	...
Vessel segments	...	1000	...	...	60.0	...	...
Rice straw[a]							
Fibers	1450	3480	650	8.5	13.5	5.1	170:1
Parenchyma	...	350	...	...	82.0	...	...
Vessel segments	...	650	...	...	40.0	...	...
White spruce[b]	...	4200	2300	...	...	...	...
Jack pine[c]	3000	...	...	40.0	...	...	75:1
Aspen[b]	...	1700	800	...	46.0	20.0	37:1
Birch[b]	...	1600	800	...	44.0	20.0	36:1
Red gum[c]	1600	...	...	32.0	...	...	50:1

[a] Wangaard, F. F., *Paper Ind.* 19: 777–784, 794 (Oct., 1937).
[b] Hägglund, E., "Holzchemie," page 20, Zwete Auflage, Leipzig, (1939).
[c] Jayme, G., and Harders-Steinhäuser, M., *Papier-Fabr. 39*, No 14: 89–95 (April, 1941).



Fourdrinier wet end showing 54-inch diameter suction couch roll and new lump breaker roll

25-Year-Old Liner Machine Beats Obsolescence

Now competitive in speed, tonnage and quality

A well-known Southern kraft mill recently completed a three-year modernization program, starting with the replacement of two-thirds of the original dryers with high-pressure dryers constructed for 150 psi, revamping of the sectional electric drive, and ending with a complete new fourdrinier wet end.

The original machine, built by Puseyjones in 1929 for a speed of 1000 F.P.M., was equipped with fourdrinier wet end for wire 240 inches wide and 80 feet long, and 36-inch suction couch roll.

The new fourdrinier of latest modern design is constructed for a wire 246 inches wide and 128 feet long with 54-inch diameter suction couch roll, and Rapidrape arrangement for fast, convenient wire change. Looking toward the future, the new fourdrinier was designed for a top speed of 2000 F.P.M.

Before modernization, the drying capacity was limited by the existing dry part comprising 58 paper and eight felt dryers of low pressure design. Seventeen of these dryers were rebuilt with new heads suitable for 75 psi and 41 were replaced with 150 lb. dryers. Six additional felt dryers were also installed. All dryers were equipped with roller bearings.

An increase of 30% in total production of liner board of higher grade has already resulted from the modernization program.

Talk over your machine rebuilding plans with Puseyjones engineers. A call or a letter will bring a nearby representative to your mill.

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Machine as originally installed in 1929

Machine rebuilt in 1954 with new fourdrinier wet end

mended for commercial use, giving chemical requirements and other pulping directions, yields, and steam, power, water, labor, and bleach demands. The utility of the pulps made from bagasse by the different processes is discussed and recommendations are made for the use of these pulps alone or in blends with long-fibered pulps to produce papers commercially acceptable in world markets. That report should be studied with care by any group or company contemplating the building of new facilities for making paper or board from bagasse. In addition, attention is directed to three recent papers by Grant (*6*) who discusses processes for pulping bagasse and other nonwoody plants.

The Peoria laboratory for a number of years has directed intensive studies to the utilization of bagasse fiber and pith. Fortunately, pilot-plant facilities are available to study all of the commercial methods used for pulping bagasse, with the exception of the Celdecor process. Bleached bagasse pulp made commercially by this process has been tested and its properties in comparison with other types of pulp will be reported. Acid processes are not satisfactory for preparing good pulps from bagasse. Nitric acid is an exception, but since this discussion is limited to commercial processes or those that have undergone large-scale trial, no further reference will be made to the nitric acid process.

Commercial pulps are prepared from bagasse by use of the following chemicals: (a) in pressure vessels—(1) lime alone or in combination with soda ash, caustic soda, sodium sulphite, (2) caustic soda, (3) kraft process chemicals—caustic soda and sodium sulphide or caustic soda and sulphur, (4) sodium sulphite with either soda ash or caustic soda as buffer; (b) Celdecor process—caustic soda and chlorine; (c) mechano-chemical process—(1) lime or lime combinations with soda ash or caustic soda, (2) caustic soda, (3) kraft chemicals.

Development work of the Peoria laboratory has been directed mainly to discovering better ways to produce pulps from nonwoody plants that will meet the rigid requirements of the United States markets, but investigations have been basic and cover a wider field(*7*). When pulps are produced by the use of lime or combinations of other chemicals with lime, they cannot be bleached and are suitable only for the manufacture of boards or coarse papers. By the proper selection of conditions, it is possible to use any of the other pulping methods, to produce either board or coarse pulps, unbleached pulps suitable for use in wrappings and board products, or bleached pulps for use in making a wide variety of printing and other specialty papers.

The selection of a suitable process for commercial use will depend on a number of factors such as kind and quality of papers needed, volume of these products that can be sold, amount of capital avail-

Table VII. Comparative Pulping Characteristics of Separated Bagasse Fibers from Various Sources

Pulping conditions: chemicals—8.7% NaOH + 4.3% Na_2S; liquids-to-solids ratio 7:1; time 1 hr. at 170°C.; bleached 70 brightness Hunter. Test basis weight 47 lb., 25 × 40—500. TAPPI methods used

Cook No.	Material; year—variety	Pulp yields, %[a]		Chemical analysis, %[b]			Bleaching, %		Strength characteristics, 600 ml. S.-R.				Density g./cc.,
		Crude	Screened 0.008 in. cut plate	Ash	Lignin	Pentosans[c]	Chlorine Consumption single[b]	Bleach yield[a]	Initial freeness, S.-R., ml.	Bursting strength, pt./ream-lb. × 100	Tensile strength, g./ream-lb.	Tearing resistance, g./ream-lb. × 100	Folding endurance, Schopper	
	Louisiana													
1402-3	Lockport, stored 1941, mixed	63.0	58.9	1.02	2.7	33.5	5.65	56.2	855	97	176	49	430	0.90
1421-2	Terrebonne, stored 1948, mixed	62.8	59.0	1.3	2.9	34.3	6.8	55.0	860	104	190	55	645	0.92
1400-1	Houma, fresh 1941, mixed	63.0	55.2	1.2	2.8	33.4	7.0	52.1	845	100	179	54	570	0.91
1406-7	Reserve, fresh 1949, mixed	63.8	58.8	1.3	3.7	34.2	7.6	54.8	865	100	188	57	620	0.91
	Florida													
1404-5	Clewiston, fresh 1948, probably F. 31-436	64.4	58.6	1.6	4.0	33.9	10.2	53.8	815	124	214	48	1000	0.96
1408-9	Clewiston, fresh 1952, Cl. 41-223	63.9	56.8	1.3	4.4	33.6	12.8	57.5	820	118	199	50	800	0.94
1413-14	Clewiston, fresh 1952, F. 31-962	61.6	55.6	1.5	4.1	31.8	9.6	52.8	835	98	170	57	640	0.88
1397, 1423	Clewiston, fresh 1953, F. 31-436	61.8	57.8	1.4	3.4	33.6	7.3	52.9	835	126	206	64	880	0.89
	Hawaii													
1398-9	Laupahoehoe, fresh 1950, mixed	62.8	56.0	1.4	3.9	32.8	10.1	53.2	835	90	162	58	405	0.86
1411-12	Oahu, fresh 1951, 1933	62.4	56.0	2.2	3.2	34.0	7.3[d]	51.8	845	97	164	60	580	0.86
	Puerto Rico													
1417-18	Aguirre, fresh 1952, mixed	58.6	49.2	1.4	4.0	33.3	12.2	45.8	835	102	182	48	615	0.89

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8. [d] Brightness 65.

Dependable Source for Chemical Raw Materials

Dr. H. W. Rowe (left), technical director, Neil H. Christian (center), general superintendent of Port Edwards, Wisc., mill, and Cecil C. Parvin, production manager, discuss future plans for Nekoosa-Edwards.

Suppliers play important part in Nekoosa-Edwards plans for future

The Nekoosa-Edwards Paper Co., Port Edwards, Wisc., one of the largest makers of fine papers in the world, started a reforestation program in 1926. Today it has enough trees growing in its forests to meet Nekoosa - Edwards' papermaking requirements for some species indefinitely.

But "Forests Forever" is only one part of Nekoosa-Edwards' far-sighted planning. Sixty-seven years' experience has proved that, while wood is vital, it takes men and machines and chemicals to make the paper.

In the words of Dr. H. W. Rowe, Nekoosa-Edwards' technical director, "The chemical industry and equipment makers have played an important part in paper progress. They will play an even greater part in the future, because the industry is becoming more and more technical minded. Our own research is continuous and far-reaching, but we also work closely with many equipment makers and chemical companies.

"Wyandotte has been one of our sources for soda ash, liquid caustic and liquid chlorine for many years. It has been our experience that they maintain uniform quality, and are dependable. Our technical standards are among the highest."

Wyandotte has been numbered among the important suppliers of chemical raw materials to the paper industry for more than 50 years. Our success in this field has been determined to a large degree by the uniformity of our products, prompt deliveries, and our all-around willingness to cooperate with customers at all levels — top management, purchasing, research, quality control, and production. May we demonstrate Wyandotte products and services to you? *Wyandotte Chemicals Corporation, Wyandotte, Michigan. Offices in principal cities.*

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able, location of the mill, kind of labor and utilities available, and other local factors. In general, the new mills will be small as compared with new mills in the United States or Europe. In deciding on the pulping process to use, in addition to cost factors such as capital investment and operation expense, it will be well to consider the simplicity of operations and equipment and the flexibility of the setup, and to plan for addition of future capacity or manufacture of higher quality merchandise as the market grows.

Pretreating Methods to Remove Pith or to Clean Fiber

The dirt and pith should be removed as much as possible before pulping. A variety of ways for doing this are available. By passing the moist bagasse from the sugar mill over shaking or vibrating screens, some of the impurities are separated. This is common practice in sugar mills to obtain pith for use in filtering muds. By the use of screens with somewhat larger holes, a larger proportion of impurities can be removed.

If the bagasse has been baled and stored, a bale breaker must be used; by passing the loosened dry bagasse over vibrating screens about one third of the pith and dirt can be removed, a practice common in pulp mills processing bagasse. Where a large excess of bagasse exists over fuel requirements, and provided the bagasse has been passed through a shredder or like mill to loosen the pith from the fiber bundles, a system of screens with larger holes will yield about one third of the processed material as fairly clean fiber.

The Peoria laboratory has developed three different procedures for obtaining clean fiber and high-grade pith (*8*). Two of these methods are applicable for use in the sugar mill, the other at the pulp mill (*9*). Lower price machinery and somewhat simpler procedures based on the principles developed are now in operation in the new mill pulping bagasse in Mexico.

The above methods are all purely mechanical. Combinations of chemical and mechanical methods are also in use. Indeed, when whole bagasse or partially screened bagasse is pulped in the presence of chemicals, a proportionately larger amount of pith than fiber is destroyed and lost by the chemical action and through washing, bleaching, and other treatments.

Another method recommended by some is prehydrolysis of the bagasse before the real pulping

Table VIII. Data on Pulping Bagasse by the Soda and by the Kraft Pressure Methods

Cook no.	Material; W = whole, F = fiber; year—variety	Cooking conditions: Chemical[a], %	Time, hr.	Temperature, °C.	Pulp yields, %[a]: Crude	Screened	Chemical analysis, %[b]: Ash	Lignin	Pentosans[c]	Bleaching, %: Chlorine consumption single[b]	Brightness, Hunter	Bleach yield,[a]	Initial freeness, S.-R., ml.	Strength characteristics, 500 ml. S.-R.: Basis weight, 25 × 40—500, lb.	Bursting strength, pt./ream-lb. × 100	Tensile strength, g./ream-lb.	Tearing resistance, g./ream-lb. × 100	Folding endurance, Schopper	density, g./cc.
1001	Terrebonne, La. W, stored 1948, mixed	12 NaOH	2	170	61	46	4.5	4.2	33	13.0	70	43	830	46	82	162	70	230	0.79
1002	Terrebonne, La. F, stored 1948, mixed	12 NaOH	2	170	62	59	1.3	2.6	32	5.4	70	57	840	46	102	184	78	660	0.90
997	Reserve, La. W (screened), fresh 1949, mixed	12 Kraft	2	170	59	50	1.8	5.5	34	15.1	70	46	840	46	85	168	76	420	0.80
998	Reserve, La. F, fresh 1949, mixed	12 Kraft	2	170	63	57	1.1	4.0	34	8.6	70	55	855	46	96	173	83	740	0.67
1135	Laupahoehoe, Hawaii F, fresh 1950, mixed	12 NaOH	2	170	62	54	1.1	5.0	31	15.1	70	50	860	47	82	162	68	300	0.79
1149	Laupahoehoe, Hawaii F, fresh 1950, mixed	12 Kraft	2	170	64	55	1.0	4.4	32	13.0	70	..	850	47	84	165	62	350	0.81
1076	Clewiston, Fla. F, fresh 1951, mixed	12 NaOH	2	170	69	61	1.5	5.6	34	26	70	50	805	47	110	190	55	980	0.84
1078	Clewiston, Fla. F, fresh 1951, mixed	12 Kraft	2	170	66	61	1.3	4.5	34	14.4	70	57	790	46	115	194	60	1120	0.90
908	Clewiston, Fla. W, fresh 1948, mixed	12 Kraft	2	170	62	52	0.9	4.5	32	12	70	49	850	46	69	152	51	160	..
909	Clewiston, Fla. F, fresh 1948, mixed	12 Kraft	2	170	66	61	1.6	3.6	33	9.0	70	57	790	46	115	196	51	970	..

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8. Samples 997 and 908 dry screened to remove pith.

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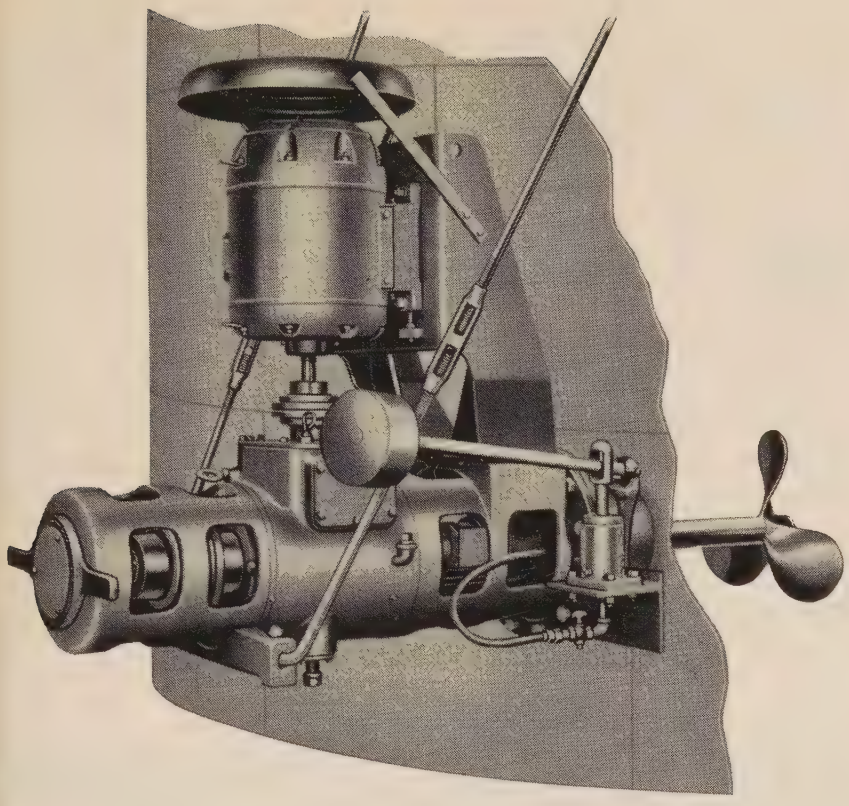
SINCE 1858 the plant of Beloit Iron Works, on the bank of the Rock River at Beloit, Wisconsin, has grown with the paper industry, and now occupies 16 acres of ground and employs over 1700 men and women. Advanced engineering and highest standards of craftsmanship are key factors in designing and building of Beloit high-speed, high-production paper machines.



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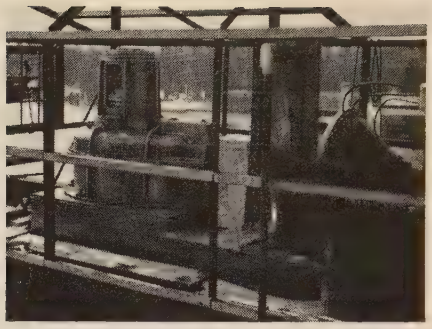

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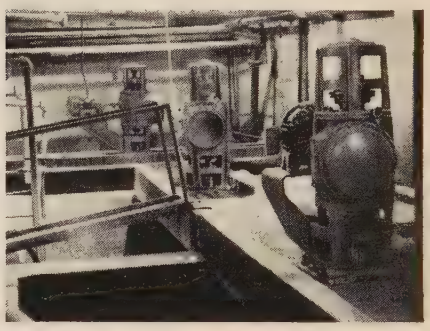

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Mechano-Chemical Process

This process (*11*) was discovered at the Peoria laboratory during the development of better methods for pulping cereal straws. It has been applied to the pulping of bagasse, although because of the denser character of the bagasse fibers more chemical and a slightly longer pulping cycle are required than for most cereal straws. The process is exceedingly simple; it uses low amounts of chemicals at atmospheric pressures for pulping periods of 30 min. to about an hour. Steam requirements have proved to be very low since a certain amount of hot black liquor is reused for pulping. Although power requirements were slightly higher than in conventional processes a new Mexican development in the processing has lowered power requirements considerably. The process is carried out in a modification of the mechanical pulpers found now in most mills, and widely used in repulping waste papers or virgin pulp. For example, when the hydrapulper is used to carry out the process, a larger rotor is required than is standard for pulping waste, with consequent higher power requirements. By use of the Mexican development mentioned, however, the power is less than is normally required for pulping waste papers. Since the pulpers can be made in sizes from 3 to 20 ft. in diameter, and since the pulper may be used also for waste papers or virgin pulps, the process is suited for both very small and very large mills.

Pulping takes place through the reaction of the pulping chemicals on fiber or fiber bundle surfaces; the greater the surface area presented the more rapid the pulping action. The violent mechanical action continuously producing fresh surfaces in the presence of chemicals during pulping accounts for the very rapid rate of pulping and also for the use of the mild pulping conditions in the mechano-chemical

Table XI. Data on Pulping Florida and Hawaiian Samples of Bagasse by Pressure and Mechano-chemical Cooking Methods

Cook no.	Material	Cooking conditions: Chemical[a], % NaOH	Time, hr.	Temperature, °C.	pH final liquor	Pulp yields, %[a]: Crude	Screen-washed	Fines	Chemical analysis, %[b]: Ash	Lignin	Pentosans	Initial freeness S.-R., ml.	Strength characteristics, 500 ml. S.-R.: Bursting strength, pt./ream-lb. × 100	Tensile strength, g./ream-lb.	Tearing resistance, g./ream-lb. × 100	Riehle ring crush, lb.	Flat crush, lb./sq. in.
						Florida Bagasse, Variety No. F. 31-436, Year 1952											
1187	Whole	8.0	5	140	...	60.7	58.9	1.8	...	...	...	685	83	166	62	42	...
1228	Whole	8.0	1	98–99	...	70.4	67.7	2.5	...	...	...	480	58 (400 ml.)	112 (400 ml.)	110 (400 ml.)	34 (400 ml.)	58 (400 ml.)
1255	Separated fiber	8.0	5	140	...	71.3	69.4	1.9	...	...	...	770	89	144	66	45	...
1229	Separated fiber	8.0	1	98–99	10.7	73.2	70.7	2.5	1.0	10.3	35	680	96	173	66	45	76
1230	Separated fiber	10.0	1	98–99	11.5	72.0	71.0	1.0	1.7	8.2	33	650	95	182	75	45	75
																	Folding
1231	Separated fiber	12.0	1	98–99	11.9	68.9	63.8	1.3	1.0	6.6	36	720	113	190	58	...	540
1244	Separated fiber	13.0	1	98–99	11.9	70.2	65.2	3.5	1.3	5.4	33	720	111	187	56	...	900
1232	Separated fiber	14.0	1	98–99	11.8	69.6	66.0	2.6	1.2	5.9	34	680	117	198	56	...	700
																	Flat Crush
						Hawaiian Bagasse, Variety No. 8560, Year 1952											
1243	Whole	8.0	1	98–99	11.1	72.1	68.4	3.7	...	...	...	510	67 (400 ml.)	129 (400 ml.)	72 (400 ml.)	35 (400 ml.)	63 (400 ml.)
1236	Separated fiber	8.0	1	98–99	11.0	76.1	74.2	1.9	...	...	...	700	79	130	92	35	72
1245	Whole	10.0	1	98–99	...	68.5	65.6	2.9	...	...	...	510	76 (400 ml.)	131 (400 ml.)	76 (400 ml.)	36 (400 ml.)	64 (400 ml.)
1239	Separated fiber	10.0	1	98–99	11.5	74.8	71.9	2.9	1.8	10.0	33	730	83	146	86	37	66
1256	Separated fiber	10.0	5	140	...	68.5	67.3	1.2	1.3	8.2	32	855	90	142	112	40	...
1240	Separated fiber	12.0	1	98–99	11.8	73.0	69.9	3.1	1.4	9.4	34	740	89	151	88	40	70
																	Folding
1241	Separated fiber	14.0	1	98–99	12.2	72.1	58.3	7.4	1.6	9.1	32	820	81	150	70	...	250
1242	Separated fiber	16.0	1	98–99	12.2	71.1	62.4	4.8	1.6	8.8	31	800	82	155	72	...	280
1251	Separated fiber	18.0	1	98–99	12.3	69.4	65 4	4.9	1.6	9.2	32	795	81	158	72	...	320

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp.

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(M-C) process. The long penetration period, needed for pulping wood chips under pressure, is entirely avoided. Experience has shown that the optimum conditions for producing a pulp by this process must be present at the start. If any condition, such as amount of chemical, concentration of chemical, consistency, temperature, available power, or speed of rotation of the pulping mass, is less than optimum, best results will not be obtained.

The process is now being used commercially to pulp straw in mills in Holland, England, and Pakistan, and a new mill to use the process is being constructed in Portugal. In Mexico a mill is producing market pulp from depithed bagasse by this process. The Mexican mill pulps at a starting consistency of 13%, other mills use 10 to 12%. In pulping bagasse, all screenings may be repulped. Yields of pulps made commercially will closely approach the crude yields shown in the tables. The Mexican company has carried on considerable development work with the result that pulps with unexpected properties, such as good tearing resistance, suitable for good wrapping papers are being manufactured. The results obtained by the use of this process are illustrated in the tables which follow and will be discussed appropriately.

CORRUGATING MEDIUM FROM BAGASSE

The stiffness and crush resistance so necessary for high-grade corrugating medium is attributed to the high-pentosan content of pulps used in its manufacture. Sugarcane bagasse and wheat and rye straw contain higher amounts of pentosans and lesser amounts of lignin than any of the hardwoods from which standard pulps for corrugating manufacture are presently made. They, therefore, represent preferred raw materials for making corrugating medium, providing proper pulping methods are used.

Several years ago at the request of the executives of the strawboard industry of the United States, the Northern laboratory undertook a study of pulping methods to bring about improved physical properties in corrugating medium made from wheat straw. This research (*12*) showed that the use of lime as a pulping chemical was responsible for the production of a softer medium, but that when caustic soda was substituted as a pulping agent the medium manufactured was stiffer and more crush resistant. When the mild pulping conditions used in the M-C process for pulping straw with caustic soda were substituted for the pressure methods conventionally used with this chemical, even higher grade pulps resulted.

Methods for producing high-grade pulps to make corrugating medium from bagasse have been extensively explored by the Peoria group. Typical results obtained are shown in Table X. It will be noted that pulping the Lockport whole bagasse with a mixture of lime and caustic soda by the M-C process produced a weak pulp as compared with pulp from the same material pulped with caustic soda alone by the conventional pressure method. When 8% caustic soda was used by the M-C process, a still better pulp was obtained. When the latter conditions were used to pulp the Lockport separated fiber, an even more acceptable pulp was obtained, as indicated particularly by the higher freeness; e.g., a pulp capable of faster running on the paper machine, and by the improved bursting and tensile strength.

The results obtained on pulping the samples of bagasse (variety F.31-436) from Clewiston, Fla., are very interesting. The samples marked "whole" had been screened before baling to remove about one third of the pith and dirt. The lower freeness and other physical properties of the pulp made from them, as compared with the pulps from cooks nos. 1255 and 1229, using separated fiber pulped by either the pressure or the M-C process, are striking. The pulp made from the whole bagasse by cooking under pressure is freer and stronger than the same material cooked with the same amount of chemical by the M-C process. This is because the pressure cook destroys more of the pith than the M-C method, as is indicated by the higher yield obtained by the latter method. When the

Table XII. Data on Large-Scale Pulping of Bagasse by the Mechano-chemical Process to Make Corrugating Medium Pulps

Cook no.	Material; W = whole, F = fiber; year—variety	Cooking conditions: Chemical, %[a]	Cooking conditions: Time, hr.	Cooking conditions: Temperature, °C.	Pulp yields, %[a]: Crude	Pulp yields, %[a]: Screened	Chemical analysis, %[b]: Ash	Chemical analysis, %[b]: Lignin	Chemical analysis, %[b]: Pentosans[c]	Initial freeness, S.-R., ml.	Strength characteristics, 500 ml. S.-R.: Basis weight, 25 × 40—500, lb.	Strength characteristics, 500 ml. S.-R.: Bursting strength, pt./ream-lb. × 100	Strength characteristics, 500 ml. S.-R.: Tensile strength, g./ream-lb.	Strength characteristics, 500 ml. S.-R.: Tearing resistance, g./ream-lb. × 100	Strength characteristics, 500 ml. S.-R.: Ricble ring crush, lb.
N. Y. College of Forestry	Clewiston, Fla. W, fresh 1952, F. 31-436	12 NaOH 8-ft. hydrapulper	1.5	99	Pulp passed over decker to remove pith and dirt		0.66	7.4	34	710	119	96	163	78	36
N. Y. College of Forestry	Clewiston, Fla. F, fresh 1952, F. 31-436	16 NaOH 8-ft. hydrapulper	1.2	99	..	..	0.60	7.8	34	820	118	111	182	80	35
N. Y. College of Forestry	Oahu, Hawaii F, fresh 1952, 8560	12 NaOH 8-ft. hydrapulper	2.0	99	..	..	1.03	11.7	33	845	119	90	161	86	34
N. Y. College of Forestry	Oahu, Hawaii F, fresh 1952, 8560 Mexican	16 NaOH 8-ft. hydrapulper	1.5	99	..	..	..	..	..	865	120	94	164	94	36
	F, stored 1952, mixed	12 NaOH 10-ft. hydrapulper	1.0	94	..	..	1.1	8.4	38	700	118	88	162	62	39
	Commercial semichemical corrugating pulp	...	..	..	..	..	1.5	14.9	22	605	118	83	148	79	31
	Commercial southern kraft liner pulp	...	..	..	..	..	1.0	7.1	13	890	116	133	192	197	31

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8.

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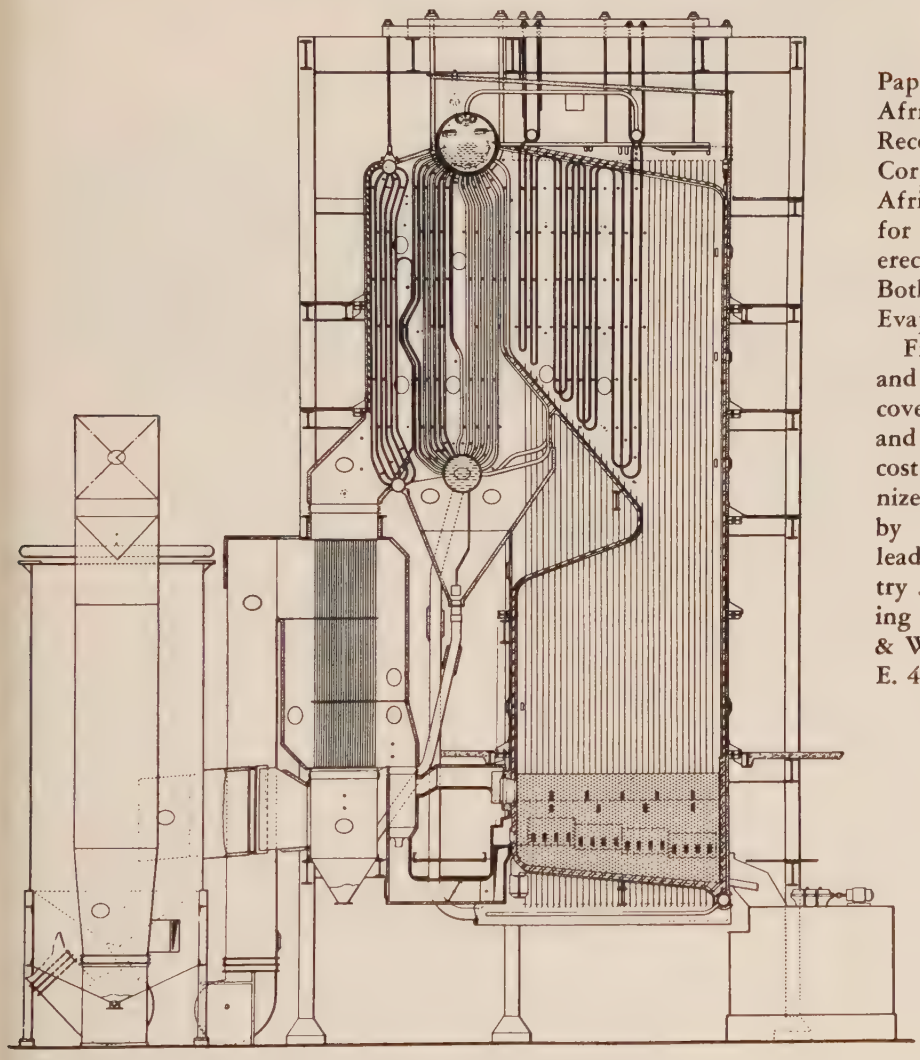

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Table XIII. Physical Properties of Corrugating Medium and Liner Boards Made Under U. S. Dept. of Agriculture RMA Contract with New York State College of Forestry, 1952

Design-nation	Kind of board	Components, %		Basis weight, lb.		Strength characteristics, 500 ml. S.-R.						
		Bagasse	Other	1000 sq. ft.	25 × 40—500	Bursting strength, pt./ream lb. × 100	Tensile strength g./ream-lb. With	Tensile strength g./ream-lb. Across	Tearing resistance, g./ream-lb. × 100 With	Tearing resistance, g./ream-lb. × 100 Across	Riehle ring crush, lb. With	Riehle ring crush, lb. Across	Caliper 0.001 in.
FFC	Corrugating	85 Florida fiber 1952, F. 31-436	15 waste corrugating	29.7	118	71	143	102	98	105	31	22	8.3
HFC	Corrugating	85 Hawaiian fiber 1952, 8560	15 waste corrugating	33.1	106	74	104	115	165	95	32	24	8.8
HFCX	Corrugating	100 Hawaiian fiber 1952, 8560	None	33.1	115	68	170	104	91	96	39	31	9.8
CC	Corrugating	85 commercial semichemical pulp	15 waste corrugating	30.3	105	70	168	99	92	111	35	24	9.2
GC	Commercial corrugating	...	...	41.3	143	53	143	33	127	199	32	18	11.0
FFL	Liner	50 Florida fiber 1952, F. 31-436	50 virgin southern kraft	42.7	148	88	188	91	166	218	40	29	11.0
FFLX	Liner	100 Florida fiber 1952, F. 31-436	None	41.3	143	85	167	110	90	94	40	36	9.8
FFLY	Liner	25 Florida fiber 1952, F. 31-436	75 virgin southern kraft	37.0	129	97	189	92	195	191	37	27	9.6
HFL	Liner	50 Hawaiian fiber 1952, 8560	50 virgin southern kraft	44.7	155	81	164	94	170	221	54	40	12.7
CL	Liner	...	100 virgin southern kraft	39.7	138	100	191	80	212	272	39	26	10.6
GL	Commercial kraft liner	...	...	43.0	149	88	158	86	262	313	32	26	13.2

pulps produced from separated fiber by the pressure and M-C processes are compared, it will be observed that the pressure method produces a slightly freer pulp, but of lower bursting and tensile strength and in slightly lower yield. When 12% lime was substituted for 8% caustic in pulping the whole Florida bagasse by the M-C method, a much weaker pulp, of lower crush resistance and freeness was produced. Both of the pulps from whole bagasse were so slow draining that they would run only slowly on the paper machine. If pulps of this quality only could be made available, a cylinder-forming machine would be preferable to a fourdrinier machine.

A comparison of the results obtained by pulping samples of Hawaiian bagasse (variety 8560) brings out essentially the same relationships as observed with the Florida bagasse.

It may be concluded from this work that pulps suitable for making low-grade corrugating medium can be made from whole or screened bagasse by cooking with lime, or lime and caustic soda or caustic soda alone, using either pressure or M-C methods. All of these pulps will drain slowly and will require the addition of waste papers or considerable washing to be run at paper machine speeds normal to modern operations. The lime-cooked pulps will be found deficient in strength, particularly crush resistance, as compared with caustic-cooked pulps. Using depithed fiber as a raw material, superior pulps are produced by the use of caustic soda with any of the pulping methods. The M-C process in general produces pulps as strong or stronger, and in higher yields.

Table XIV. Physical Properties of 200-Lb. Test Liner Boards Made Under U. S. Dept. of Agriculture RMA Contract with New York State College of Forestry, 1952

Combination	Bursting strength, p.s.i.	G.E. puncture (Beach)	Flat crush, p.s.i.
FFL-FFC	257	204	71
CL-FFC	265	219	77
GL-FFC	243	235	76
HFL-HFC	216	212	65
CL-HFC	253	233	68
GL-HFC	265	232	65
GL-HFCX	229	271	88
FFL-CC	269	201	56
HFL-CC	226	185	52
CL-CC	262	224	63
GL-CC	241	228	64
FFL-GC	253	176	27
HFL-GC	225	203	33
FFLX-GC	197	151	25
FFLY-GC	241	185	25
CL-GC	233	203	27
GL-GC	240	203	28

SEMICOMMERCIAL PRODUCTION OF SHIPPING CONTAINERS FROM FLORIDA AND HAWAIIAN BAGASSE

A contract was made by the U. S. Government with the New York State College of Forestry, Syracuse, N. Y., under the Research and Marketing Acts to carry out the manufacture of shipping containers using bagasse as a raw material. Based on data, of which the results shown in Table XI are representative, it was decided to use the M-C process to produce both corrugating and liner-board pulps. Tonnage lots of both Florida and Hawaiian bagasse were secured. A portion of the Florida whole bagasse was depithed at Syracuse, using the hydrapulper method developed by the Northern laboratory. The Hawaiian Sugar Planters' Association used the same method in their Hawaiian pilot plant and shipped both whole and depithed bagasse to Syracuse.

The lots of bagasse were pulped at Syracuse in an 8-ft. hydrapulper which was somewhat deficient in rotor speed and in power. The results of the physical tests on some of the representative pulps so produced are given in Table XII. Pulp made from the whole Florida bagasse was so slow draining that it would not run either on the fourdrinier or the cylinder wet end of the paper machine. The pulp also contained grit. Only by rewashing the pulp, after suitable dilution, by passage twice over a decker could the pulp be made free enough to run and produce satisfactory board. The physical properties of this pulp given in Table XII are representative of the washed pulp and are very similar to the properties obtained by pulping depithed Florida fiber under similar conditions. The whole bagasse actually was thus depithed by a combination of chemical and mechanical methods. The corrugating pulps from whole bagasse and from separated fiber were produced by using 12% caustic soda on the basis of oven-dry material. The liner-board pulps were made from separated fiber with 16% caustic. It will be observed that the pulps obtained by cooking with the higher percentage of chemical are somewhat freer and stronger.

In this connection it is interesting to compare the results obtained commercially in Mexico by pulping with 12% caustic in a 10-ft. hydrapulper, using Mexican bagasse separated fiber.

In making the corrugating medium at Syracuse, 85% bagasse pulp and 15% waste corrugating were used as the furnish

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excepting in one case (HFCX) when 100% Hawaiian corrugating pulp was used. Liner boards from both Florida and Hawaiian fiber were made from a mixture of 50% bagasse and 50% virgin kraft wood pulp, and in two cases with Florida bagasse, 25 and 75% kraft pulp, respectively. As a control on machine operation, corrugating medium was made from 85% commercial semichemical hardwood pulp and 15% waste corrugating, and liner board from 100% virgin kraft wood pulp. The physical properties of the boards made are given in Table XIII. The various corrugating media and liner boards were combined into 200-lb.-test container board in a commercial box plant. The physical properties of the various combinations are shown in Table XIV. The superior strength of the combinations using corrugating medium from bagasse, as compared with medium made from semichemical hardwood pulp or commercial corrugating medium, is significant. The combination GL-HFCX, with a crush resistance of 88, is remarkable and this board is actually too stiff to be practical for use in ordinary shipping container manufacture.

Three sizes of containers were manufactured commercially from these combinations. The containers were subjected to laboratory tests and to commercial shipping tests. Results were satisfactory in all cases, showing that corrugating medium made from depithed bagasse by the M-C process would meet or surpass the highest present commercial standards. The liner boards made from 50% or more bagasse were not the equal in quality to 100% kraft liner board, but they would meet most of the less exacting world industrial requirements. Excepting for tearing resistance, the liner board (FFLY, Table XIII), containing 25% bagasse and 75% virgin kraft, compares favorably with the properties of 100% kraft liner.

FINE PULPS FROM BAGASSE FOR UNBLEACHED OR BLEACHED PAPERS

Unbleached or bleached pulps suitable for use in printing and other fine papers can be made from either whole or partly screened bagasse or better, from pith-free fiber. The effects of pith in increasing chemical costs, in producing slow draining, weak pulps, and in causing difficulties in bleaching have already been discussed. As higher grades of pulp are required, these difficulties will, of course, become more acute. For obtaining fine pulps from bagasse, the chemicals, caustic soda, kraft, or neutral sulphite, may be used with the conventional pressure processes. The amounts of chemicals required will increase as higher quality pulps are produced. The Celdecor and M-C processes also produce fine pulp, using more chemical than for preparing pulps for corrugating media or liner boards. Some of the pulps produced by these various methods may be bleached to a brightness of about 70 by a one-stage process. Depending on the amount of pith, dirt, and lignin present, others will not easily produce bright pulps except by use of multi-stage bleaching processes. To obtain a brightness of 80 to 83, the conventional three-stage bleaching process generally will be found satisfactory with pulps made from depithed fiber. The pulps produced by the three-stage process are stronger and require less chlorine than when bleached to the same brightness by the one-stage process. Pulps containing high amounts of dirt and pith require larger amounts of chlorine for bleaching, which tends to produce weaker pulps in lower yields. In some cases it appears impossible to obtain pulps of high brightness by starting with low-grade, dirty bagasse. Satisfactory pulps for fine papers cannot be made by the use of lime or mixtures of lime with caustic chemicals.

Fine Pulps from Depithed Fiber

In order to obtain a comparison between pulping depithed fiber under pressure and by the M-C process, tests were made using kraft chemicals and caustic soda.

The data, given in Table XI, show that in general the crude yields of pulp obtained by the M-C process are higher than

Table XV. Comparison of Results of Pulping Bagasse Fiber by Conventional Pressure Methods and the Mechano-chemical Process to Produce Fine Paper Pulps

Cook no.	Material: Variety	Material: Method	Cooking conditions: Chemical,[a] %	Cooking conditions: Time, hr.	Cooking conditions: Temperature, °C.	Pulp yields, %[a]: Crude	Pulp yields, %[a]: Screened	Chemical analysis, %[b]: Ash	Chemical analysis, %[b]: Lignin	Chemical analysis, %[b]: Pentosans[c]	Bleaching, Chlorine consumption single[b]	Bleaching, Brightness Hunter	Initial freeness S.-R., ml.	Basis weight, 25 × 40—500, lb.	Strength characteristics, 500 ml. S.-R.: Bursting strength, pt./ream-lb. × 100	Tensile strength, g./ream-lb.	Tearing resistance g./ream-lb. × 100	Folding endurance, Schopper	Density, g./cc.
1249	Florida, variety F. 31-436, CD. 9941	Pres.	13 kraft	1	170	61.9	55.8	1.3	3.2	32.0	8.7	70	810	47	115	186	60	680	0.89
1232	"	M-C	14 NaOH	1	99	69.6	65.0	1.2	5.9	34.0	12.0[d]	70	850	47	121	193	59	910	0.89
998	Louisiana,	Pres.	12 kraft	2	170	63.3	56.6	1.1	4.0	34.5	8.6	70	855	47	96	173	83	740	0.87
985	CD. 8953	M-C	15 NaOH	3/4	98	72.1	55.4	1.4	6.1	31.7	..	..	810	46	90	166	82	380	0.83
1417–1418	Puerto Rican, CD. 10081	Pres.	13 kraft	1	170	58.6	49.2	1.4	4.0	33.3	12.2	70	835	47	102	182	48	615	0.89
1363	"	M-C	16 kraft	3/4	99	69.2	58.1	1.3	6.5	33.6	14.3	70	790	46	93	173	64	480	0.83
1397–1423	Florida, variety F. 31-436,	Pres.	13 kraft	1	170	62.0	57.8	1.4	3.4	33.6	7.3	70	835	47	126	206	64	880	0.90
1394	CD. 10366	M-C	14 NaOH	3/4	99	69.3	61.1	1.0	6.0	32.9	12.6	70	780	46	105	174	63	660	0.87
909	Florida,	Pres.	12 kraft	2	170	66.0	60.6	1.6	3.6	33.0	9.0	70	790	46	115	196	51	970	0.96
921	CD. 7892	M-C	15 kraft	3/4	99	71.4	58.0	..	5.1	36.0	12.5	70	780	46	106	188	44	980	0.66
1147	Hawaiian,	Pres.	8 kraft	2	170	70.1	36.5	1.6	9.3	31.3	25.4[d]	70	830	47	70.5	151	52	150	0.80
1148	CD. 9333		10 kraft	2	170	66.9	44.3	1.2	6.9	31.5	13.0[d]	70	840	47	79.5	162	59	270	0.80
1149	"		12 kraft	2	170	64.0	55.2	1.0	4.4	31.8	6.4[d]	70	850	47	84.5	165	62	350	0.81
1150	"		14 kraft	2	170	61.4	56.4	1.0	2.6	32.9	3.4[d]	70	850	47	88.5	154	62	480	0.84

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8. [d] Three-stage bleach.

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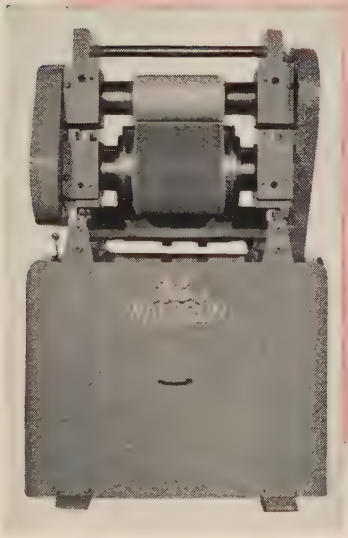

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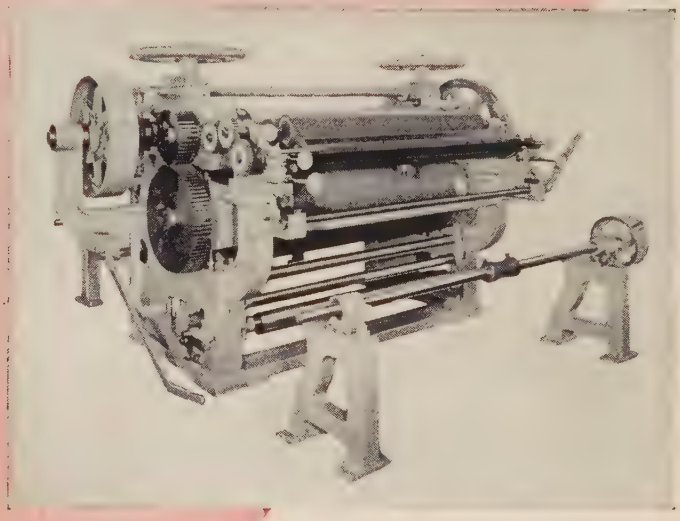

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Table XVI. Data on Large-Scale Production of Fine Bleached and Unbleached Pulps from Bagasse Fiber by the Mechano-chemical Process and the Celdecor Process

Cook no.	Material; year—variety	Cooking conditions: Chemical,[d] %	Cooking conditions: Time, min.	Chemical analysis[b]: Ash, %	Chemical analysis[b]: Lignin, %	Chemical analysis[b]: Pentosans,[c] %	Brightness Hunter, %	Initial freeness S.-R., ml.	Strength characteristics, 500 ml. S.-R.: Bursting strength, pt./ream-lb. × 100	Strength characteristics, 500 ml. S.-R.: Tensile strength, g./ream-lb.	Strength characteristics, 500 ml. S.-R.: Tearing resistance, g./ream-lb. × 100	Strength characteristics, 500 ml. S.-R.: Folding endurance, Schopper	Density, g./cc.
1062	Clewiston, Fla. Separated fiber 1950–51, mixed	15 NaOH	60	...	...	..	..	750	116	192	48	980	...
1062–1075	Composite bleached at Forest Products Laboratory	15 NaOH	60	1.3	5.7	33	..	730	115	186	56	1060	0.89
1062–1075	After bleaching 3 stage at FPL	11 chlorine	..	0.6	0.3	34	81	700	121	190	58	1120	0.97
1139	Clewiston, Fla. Separated fiber 1950–51, mixed	15 NaOH	50	...	...	..	..	800	116	192	56	930	...
1140–1141	Screenings from cook No. 1139 Cooked separately	10 NaOH	45	...	...	..	..	890	116	192	66	700	...
New York College of Forestry	Clewiston, Fla. Separated fiber 1952, F. 31-436	16 NaOH 8-ft. hydrapulper	60	1.4	6.1	32	..	840	115	184	56	805	0.89
New York College of Forestry	After bleaching 3 stage at St. Regis Paper Co.	13 chlorine	..	0.2	1.4	33	80	770	126	207	59	1480	0.92
	From Pakistan, dry-screened bagasse, Celdecor process	...	..	1.2	0.3	34	78	810	61	130	56	80	0.82

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8.

those obtained by the pressure process, as is also often the case with respect to screened yields. It must be noted that the results shown in this table may be somewhat misleading, as compared with results obtained in commercial practice, since in commercial practice the screenings obtained in one cook would be returned to the succeeding cook for repulping. On the other hand, the lignin contents of the pressure-cooked pulps are lower in all cases as are also the chlorine requirements for bleaching in one stage to 70 brightness. The relation between the other physical characteristics of the pulps made by the different methods is somewhat indeterminate, depending on the particular sample of bagasse which was pulped.

This table also contains data on pulping of Hawaiian bagasse under pressure, using kraft chemicals in increasing concentrations. It will be noted that the first two cooks, using 8 and 10% kraft chemicals were not satisfactory as indicated by the low yields of screened pulps. With 12 and 14% kraft chemical, the crude yields decreased and the screened yields increased; the lignin content of the pulps and the chlorine requirements for bleaching both decreased. The pulp produced with 14% kraft chemical was best from the standpoint of physical properties. Pulping of the Hawaiian bagasse was more difficult than for the other samples of bagasse studied and the pulp produced was not as strong.

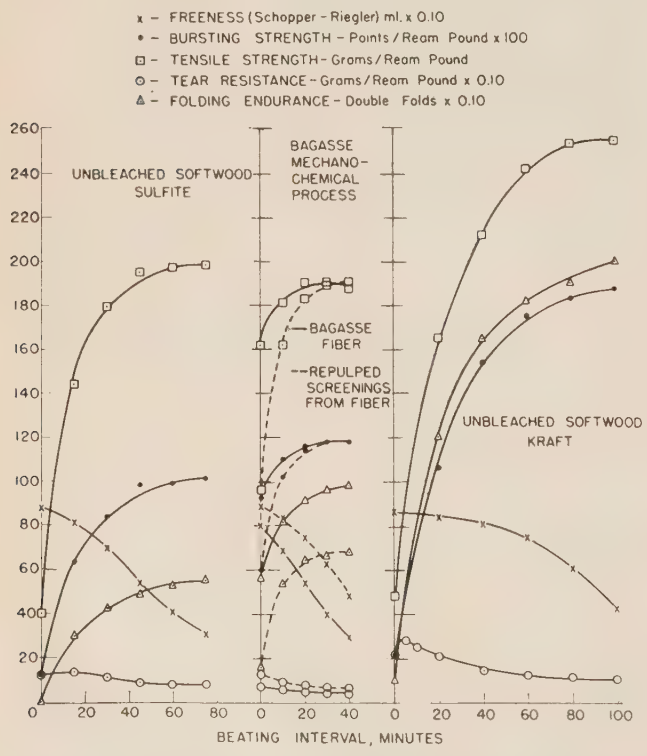
x – FREENESS (Schopper - Riegler) ml. x 0.10
• – BURSTING STRENGTH – Points / Ream Pound x 100
□ – TENSILE STRENGTH – Grams / Ream Pound
⊙ – TEAR RESISTANCE – Grams / Ream Pound x 0.10
△ – FOLDING ENDURANCE – Double Folds x 0.10
UNBLEACHED SOFTWOOD SULFITE
BAGASSE MECHANO-CHEMICAL PROCESS
BAGASSE FIBER
REPULPED SCREENINGS FROM FIBER
UNBLEACHED SOFTWOOD KRAFT
BEATING INTERVAL, MINUTES

Fig. 1. Comparison of strength data on mechano-chemical unbleached pulps from depithed bagasse fiber and repulped screenings with commerical unbleached softwood pulps

Referring to the effect of screenings, Table XVI presents some interesting data. In preparing a rather large lot of M-C pulp for bleaching and manufacturing into paper in a cooperative study at the Forest Products Laboratory, Madison, Wis., 14 cooks (1062–1075) were made on Florida bagasse. In making the composite lot, the screenings from each cook were returned to the succeeding cooks but in the first cook no. 1062, screenings were not repulped. It will be noted that the composite lot and the pulp from the first cook agree in freeness, bursting, and tensile strength, but the composite is superior in tear and in fold resistance. When the latter lot was bleached at the Forest Products Laboratory, the pulp was found to be lower in freeness but superior in other physical properties to the unbleached pulp.

In order to determine directly the effect of repulping screenings, cook 1139 was carried out without repulping the screenings. The screenings were repulped in cooks 1140–1141. The pulp prepared from the screenings had higher freeness, the same bursting and tensile strength properties, considerably higher tearing resistance, and somewhat lower double fold. The screenings come largely from the dense rind fibers of the bagasse which are somewhat difficult to penetrate. It has long been known that the rind fibers contain fiber elements of a longer dimension than the fibers from the fibrovascular bundles, an effect which shows up clearly in the higher tearing resistance of the pulp from screenings.

The properties of another composite pulp made from bagasse fiber in the 8-ft. hydrapulper at the New York State College of Forestry, in which the screenings were returned to the succeeding cooks, are shown in this table. Properties of the bleached pulp produced from it in a three-stage process at one of the plants of the St. Regis Paper Co. are also given. It will be noted that the unbleached pulp was similar in properties to the unbleached pulp used at the Forest Products Laboratory. The New York State College of Forestry pulp had higher physical strength properties after bleaching. In this connection, reference is made to the bleached Celdecor commercial Indian bagasse pulp which is softer and has considerably lower strength properties than the bleached M-C pulps.

A study was also made using increasing amounts of chemi-

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cals in pulping depithed fiber by the M-C process. Data representative of this study are presented in Table XVII, a review of which shows that there is little decrease in yield or increase in physical properties of pulps after the optimum amount of chemical has been used.

When pressure pulping is used pulp yields are lower and a smaller amount of screenings is obtained, which appears to be due to a better penetration of the rind fibers and probably to greater destruction of the fibrovascular bundle fibers. By increasing the severity of the pressure cooking conditions, the yield of pulp is further decreased. On the other hand, with the mild conditions of the M-C process, it is more difficult to penetrate rind fibers, but less destruction to the fibro-vascular bundle fibers results. The over-all yields of screened pulps are not only higher in the latter process, but by repulping the screenings a still larger yield of pulp will be obtained as compared with pressure cooking methods. While pressure cooking reduces the amount of chlorine required for bleaching, it is evident that extremely high-grade unbleached and bleached pulps can be made from depithed bagasse fiber by the M-C process.

Figure 1 illustrates the strength characteristics of unbleached depithed fiber bagasse pulp produced by the M-C process as compared with unbleached commercial softwood sulphite and commercial softwood kraft pulps. The bagasse pulp is superior to the unbleached sulphite pulp in all of its properties excepting tearing resistance but is not as strong as the kraft wood pulp. Pulps made from the better grades of wheat (*13*) straw by the M-C process compare closely in physical properties with pulps made from depithed bagasse.

FINE PAPERS FROM BAGASSE

Wrapping and Bag Papers

The composite pulp referred to in Table XVI, cooks 1062 to 1075, was blended with commercial kraft wood pulp to produce wrapping and bag papers on the paper machine of the Forest Products Laboratory. The wrapping paper was made from a blend of 50% bagasse pulp and 50% kraft pulp, both unbleached, and as a control this grade of paper was also made from 100% kraft wood pulp. The bag paper was made from a blend of 25% bagasse pulp and 75% kraft wood pulp and a control run of 100% kraft wood pulp was also made. It will be noted from the data in Table XVIII that, with the exception of tearing resistance, the wrapping and bag papers made with bagasse have somewhat better strength characteristics than those made from 100% kraft wood pulp. The table also includes tests made on wrapping and bag papers produced in Peru from mixtures of bagasse pulp, kraft pulp, and waste. The Philippine company producing paper from bagasse reports tests made on handsheets from blends of Celdecor bagasse pulp and American kraft wood pulp. In this case also the use of mixtures of bagasse pulp and kraft wood pulp produced wrapping papers superior to papers made from 100% wood pulp, excepting in tearing resistance. This same phenomenon has been observed in bags and wrappings made from blends of M-C wheat straw (*13*) pulp and kraft softwood commercial pulps. Wheat straw pulps produced by the neutral sulphite process in Italy are frequently blended with kraft wood pulps in order to produce better papers for wrapping and bag.

The reason for this apparent paradox is that the fibers of the straw and bagasse pulps greatly improve the formation of papers made from the blends, so that the kraft fibers contribute a higher proportion of their inherent strength to the papers so made.

This finding is of great commercial importance because it indicates the possibility of manufacturing very high-quality bag and wrapping papers by the use of properly prepared blends of bagasse pulps and wood pulps. This could lower the import requirements of kraft wood pulps in countries where long-fibered pulp woods are not available. Pulps from such fibers as abaca, sisal, hemp, ramie, and flax can be added to the shorter-fibered bagasse pulps to produce papers of extremely high tearing resistance (*14*).

Newsprint

Much of the discussion of the use of bagasse for making newsprint has appeared in the lay press and is the cause of a great deal of confusion, which arises largely from the definition of the word "newsprint."

It has been demonstrated numerous times that a paper can be made from 100% bagasse pulp which will run on fairly high-speed printing presses such as are used by newspaper publishers (*15*). If sufficient filler and opacifying material are added to the bagasse pulp, the showthrough and ink penetration of the paper will be satisfactory, but it will not have the same appearance or feel generally associated with newsprint. Newsprint as known in most countries consists of a blend of mechanical pulp, 75 to 85%, and chemical pulp, 15 to 25%. When northern spruce or hemlock groundwood is used, the chemical pulp is nearly always spruce or hemlock sulphite. When southern pine or eucalyptus groundwood is used, the chemical

Table XVII. Data on Pulping of Depithed Bagasse Fiber by Mechano-chemical Process

Cook no.	Material variety	Cooking conditions: Chemical,[a] %	Time, hr.	Temperature, °C	Pulp yields, %[a]: Crude	Screened	Chemical analysis, %[b]: Ash	Lignin	Pentosans[c]	Chlorine consumption single[b]	Bleaching, %: Brightness Hunter	Bleach yield[a]	Initial freeness, S.-R., ml.	Basis weight, 25 × 40—500, lb.	Strength characteristics, 500 ml. S.-R.: Bursting strength, pt./ream-lb. × 100	Tensile strength, g./ream-lb.	Tearing resistance, g./ream-lb. × 100	Folding endurance, Schopper	Density, g./cc.
1231	Florida, variety	12 NaOH	1	99	68.9	63.8	1.0	6.6	36.0	20.8	70	54.0	720	47	113	190	58	540	0.87
1244	F.31-436,	13 NaOH	1	99	70.2	65.2	1.3	5.9	33.0	20.1	70	57.0	720	47	111	187	56	900	0.89
1232	C.D. 9941	14 NaOH	1	99	69.6	65.0	1.2	5.9	34.0	12.0[d]	70	56.0	850	47	121	193	59	910	0.89
1394	Florida, variety	14 NaOH	3/4	99	69.3	61.1	1.0	6.0	32.9	17.5	70	55.9	780	46	105	174	63	660	0.87
1395	F.31-436,	15 NaOH	3/4	99	70.5	63.6	0.8	5.6	32.6	18.0	70	57.0	790	47	107	176	65	680	0.87
1396	C.D. 10366	16 NaOH	3/4	99	68.6	62.3	0.9	6.1	31.9	18.3	70	57.0	770	46	105	172	56	660	0.85
1241	Hawaii, variety	14 NaOH	1	99	72.1	58.3	1.6	9.1	32.0	18.1[d]	70	49.7	830	46	81	150	70	250	0.72
1242	8560,	16 NaOH	1	99	71.1	62.4	1.6	8.8	31.0	17.4[d]	70	55.4	800	47	82	155	72	280	0.71
1251	C.D. 9992	18 NaOH	1	99	69.4	65.4	1.6	9.2	32.0	11.9[d]	70	55.8	790	46	81	158	72	320	0.72

[a] Basis oven-dry raw material. [b] Basis oven-dry screened pulp. [c] Pentosans = furfural × factor 0.8. [d] Three-stage bleach.

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pulp is bleached kraft. The properties of ink absorption, high opacity, and softness of standard newsprint are to be attributed almost entirely to the mechanical pulp. In general, the printing quality of newsprint improves as the amount of chemical pulp is reduced.

From the commercial standpoint, the question of using 100% bagasse pulp for the manufacture of newsprint, magazines, or other types of low-quality printing papers will depend on whether the publishers in the particular country will accept this type of product in lieu of a product composed largely of mechanical pulp. If mechanical pulp is entirely unavailable, then there should be no question of the publishers' attitude. On the other hand, from a long-term view, mechanical pulp can be produced at a lower cost than any chemical pulp. Thus it might be that for a time a country, being deficient in mechanical pulp, would use paper made entirely from bagasse pulp until papers based on a larger percentage of groundwood became available. History shows that newspaper publishers constantly demand lower priced and better newsprint which will result from lower priced, or available mechanical pulps.

There seems to be no doubt that the chemical pulps such as unbleached sulphite or bleached kraft, presently used in the manufacture of newsprint in various countries, can be replaced by bleached bagasse or bleached straw pulps. Indeed, there is reason to believe, that because of the high tensile strength of the bleached pulps made by the M-C process from bagasse and straw, some of the weaker groundwoods such as eucalyptus or southern pines would be converted into higher grade printing papers than are presently made.

Tests have been made on making newsprint from mixtures of bagasse and mechanical wood pulps on the paper machines both at the Forest Products Laboratory and the New York State College of Forestry. The properties of the bleached bagasse pulps used in making these papers are reported in Table XVI. The proportions of bagasse and mechanical pulps used and the characteristics of the papers are given in Table XIX. The papers made from these blends meet the printing and physical standards for newsprint in the United States. The formation of the papers made with bagasse pulp is better than the formation obtained with the all-wood pulp furnish, because of the action of the fine bagasse fibers in improving formation. Improvements in formation of newsprint improve printing qualities, particularly of half tones. Tests in an effort to produce a somewhat stiffer newsprint from southern pine groundwood show that addition of 15 to 20% bleached bagasse pulp to a furnish of 80% mechanical pulp and 20% bleached kraft pulp produced a sheet comparable to Canadian newsprint.

The physical properties of newsprint made in Peru and in India from blends of bagasse and other fibers are shown in Table XIX. In addition the properties of three of the "newsprint" papers made by the U. S. National Bureau of Standards (*16*) from 100% bagasse are included. Paper no. 1 of the Bureau of Standards' group was judged to be best from the standpoint of printing, softness, and opacity. This paper had a very high ash content, the opacity having been brought up by the use of titanium dioxide. An analysis of the results would indicate that had equal amounts of filler and titanium dioxide been used in making the other two papers, equal opacity and printability would probably have been obtained. Finally, this table also gives the properties of commercial newsprint used in the United States.

Writing and Other Fine Papers from Bagasse

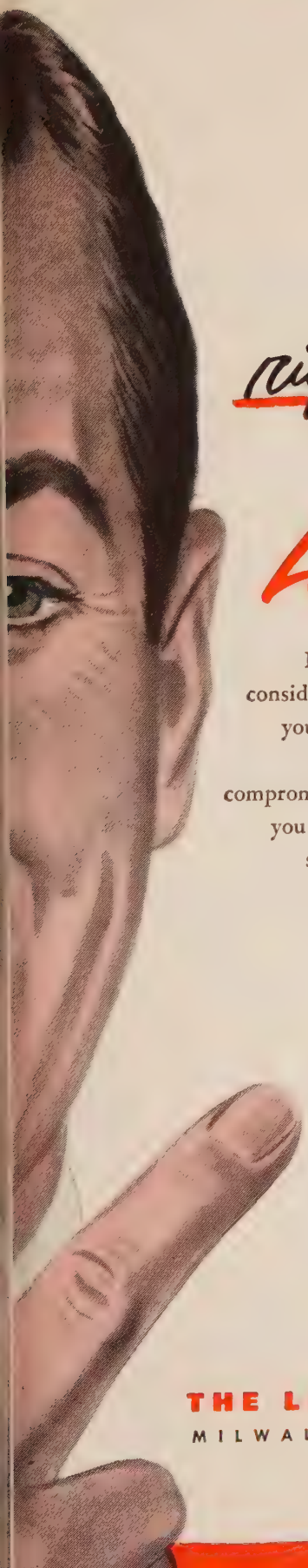
Part of the lot of pulp bleached at the Forest Products Laboratory, cooks 1062–1075, Table XVI, was also used for the manufacture of bond, magazine-book, and printing papers on the Forest Products Laboratory paper machine. The physical characteristics of these papers are reported in Table XX. The bond and magazine-book papers made with blends of bagasse pulp compared favorably with the same grade of papers made entirely from wood pulps, and showed improvements in formation. The paper, MR-3590, using 100% bagasse pulp was lacking in opacity and had tendency to be somewhat dense with a hard surface, but when 25% of clay was added to the pulp, MR-3591, a very good opaque printing paper was obtained. This table also reports the tests made on a printing paper composed of 100% bagasse made in Peru.

Because of the information now available on the commercial use of bagasse pulps and because of the very great similarity of pulps produced from depithed bagasse and from straw, it is entirely safe to conclude that a very wide field is open for the use of unbleached and bleached bagasse pulps, particularly those made from depithed fiber, for the manu-

Table XVIII. Kraft Bag and Wrapping Papers Made in Part from Unbleached Bagasse Pulp

Place made	Kind of paper	Run no.	Furnish		Freeness	Basis weight, 25 × 40—500, lb.	Bursting strength, pt./ream-lb. × 100	Physical characteristics							
			Bagasse, %	Wood sulphite %	Canadian, ml.			Tensile strength, kg.—15 mm. width		Tearing resistance, g.		Folding, endurance Schopper		Density, g./cc.	Caliper, 0.001 in.
								MD	CD	MD	CD	MD	CD		
Kraft Bag and Wrapping Papers Made in Part from Unbleached Bagasse Pulp															
USDA-FPL, Madison, Wis.	Bag	MR-3643	25	75	...	54.0	96.7	11.9	4.5	58.9	78.1	960	400	0.75	4.0
		MR-3645	...	100	...	51.8	75.9	11.3	3.5	74.2	106.0	1100	140	0.70	4.1
	Wrapping	MR-3644	50	50	...	98.7	101.0	21.1	8.7	122.0	137.0	1200	800	0.79	6.9
		MR-3646	...	100	...	104.0	78.4	18.5	7.1	227.0	273.0	...	...	0.71	8.1
Peru	Bag	8P	67	28	...	48.0	49.0	6.2	2.9	41.4	54.0	150	27	0.62	4.3
	Wrapping	3C	55	15	...	107.0	42.0	10.8	6.5	111.0	140.0	...	...	0.64	9.5
Handsheets Prepared from Blends of American Wood Kraft and Celdecor Bagasse Pulps															
Philippine[a]	...		...	100	630	39.2	89.0	5.6	...	107.0	...	2970	...	0.55	3.9
			100	...	510	36.9	87.0	5.1	...	51.0	...	450	...	0.46	4.5
			50	50	520	39.2	101.0	7.1	...	53.0	...	1610	...	0.45	4.8
			75	25	460	39.8	89.0	6.3	...	47.0	...	2170	...	0.52	4.2

[a] "Paper from Bagasse," *World's Paper Trade Rev.* 134, No. 13: 860 (Oct. 5, 1950).



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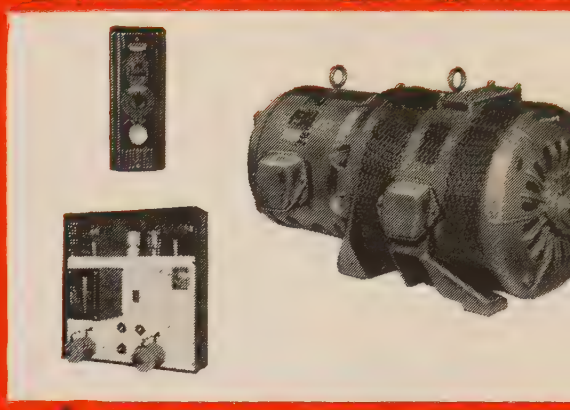

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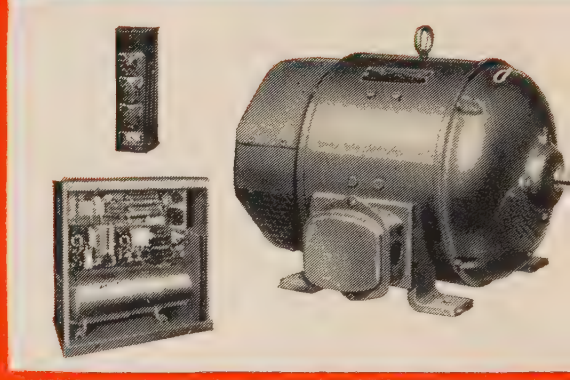

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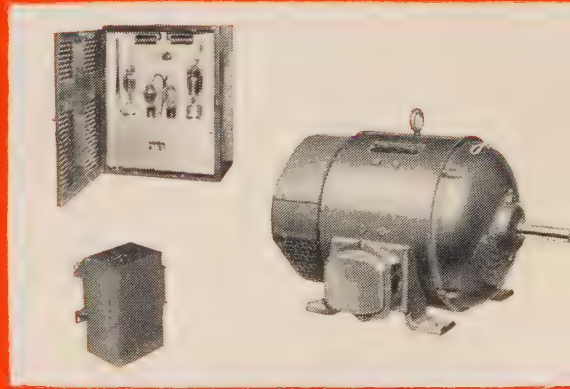

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facture of fine and specialty papers. Tabb (*17*) has recently given a very good summary of the properties of straw pulps and how they may be used as blends with other pulps to produce fine and specialty papers.

Because of the character of the bagasse fiber, the addition of it in rather small percentages; e.g., in the neighborhood of 20 to 30%, to almost any pulp with which it may be blended will be found to improve the formation characteristics of papers made from it. Improvement in formation makes better papers for printing and also for waxing. The high-pentosan content of pulps made from bagasse makes their beating or refining possible in much less time and at lower cost than is possible with wood pulps. Experience shows, however, that it is desirable to beat these pulps. Best results are not obtained by using unbeaten unbleached or bleached bagasse pulps as blends with other pulps. The high-pentosan content of these pulps also is responsible for their tendency to form denser papers which points to their use in bringing about a better handle in many kinds of papers, such as bank, bond, writing of all sorts, and account books. Pulps of this sort are useful in producing a hard surface on tag papers and in closing the surface of papers used for coating or for lithography.

Bagasse pulps, particularly those made by the M-C process, are suited for making glassine. Glassine papers are made from straw pulps of similar characteristics in Italy and Germany.

If it becomes necessary to make papers using bagasse alone, the lack of opacity in such papers and their tendency to be dense can be overcome by the addition of well-known mineral fillers. The fine fibers of the bagasse pulp result in a higher retention of fillers, and generally the cost of mineral filler is below the cost of bleached pulp. The softness of papers made from 100% bagasse pulp can be controlled to a considerable extent also by the addition of fillers.

SUMMARY

From the standpoint of necessity owing to unavailability of wood or other pulps, it is

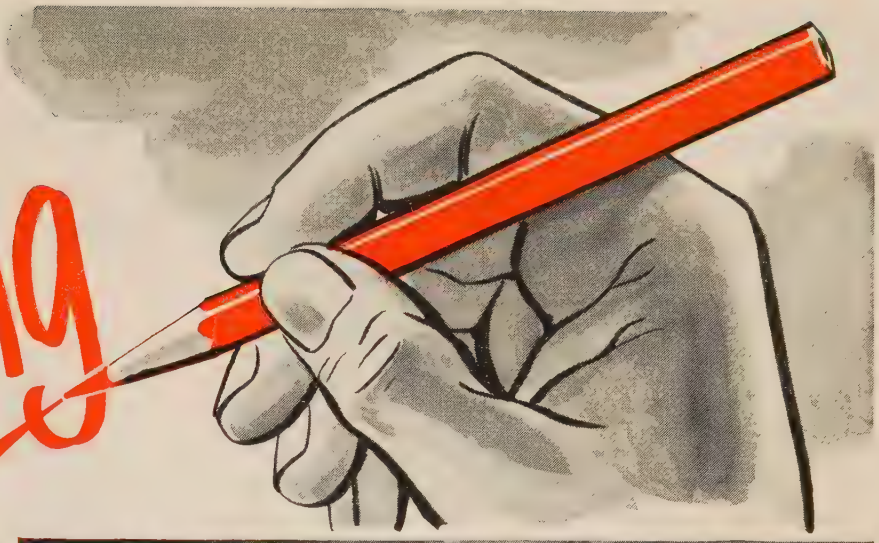
Table XIX. Newsprint Papers Made from Bleached Bagasse in Whole or Part

Place made	Run No.	Furnish				Physical characteristics																Ash, %
		Bagasse, %	Wood sulphite, %	Ground-wood, %	Other, %	Basis weight, lb. 25 × 40—500	Basis weight, lb. 24 × 36—500	Bursting strength, p.s.i.	Tensile strength, kg.—15 mm. width MD	Tensile strength, kg.—15 mm. width CD	Tearing resistance, Elmendorf MD	Tearing resistance, Elmendorf CD	Folding endurance, Schopper MD	Folding endurance, Schopper CD	Density, g./cc.	Caliper, 0.001 in.	Opacity contrast ratio, %					
USDA-FPL, Madison, Wis.	MR-3652	30	..	70 spruce-aspen	...	39.5	34.1	12.7	3.9	2.2	25.6	28.8	8	3	0.53	4.1	...					..
	MR-3654	30	..	70 spruce-tupelo	...	30.0	25.9	9.1	3.2	1.7	22.4	25.6	3	1	0.40	4.1	...					...
	MR-3653	...	20	80	...	39.9	34.5	11.2	3.9	2.0	28.8	33.3	6	3	0.49	4.5	...					...
N. Y. State	MR-9	30	..	70	...	39.6	34.2	9.5	3.1	2.1	16.0	17.3	3	2	0.58	3.8	(85 Brt.) 97					8.0
College of Forestry, Syracuse	MR-8	...	20	80	...	39.0	33.7	8.0	2.5	1.8	19.8	20.5	2	3	0.55	3.9	97					5.4
Peru	...	80	10	...	10 waste	42.0	36.3	15.4	4.1	2.3	22.7	25.6	19	8	0.72	3.2	...					...
India	...	70	..	...	30 bamboo	45.0	38.9	12.6	3.8	2.9	32.0	37.0	10	8	0.77	3.2	... (MgO)					1.2
U. S. Dept. Commerce National Bur. of Standards Washington, D. C.	1	100	..	...	...	41.4	35.8	11.0	3.9	2.1	29.0	43.0	13	7	...	3.2	92					13.2
	2	100	..	...	...	38.4	33.4	8.0	3.0	1.8	19.0	18.0	7	5	...	2.9	78					5.4
	3	100	..	...	...	49.5	42.8	13.5	4.1	3.0	25.0	24.0	12	11	...	4.1	82					14.9
Commerical news	...	...	30	70	...	37.6	32.5	7.0	2.4	1.2	19.0	23.0	5	1	...	3.5	90					0.24

Table XX. Bond and Other Printing Papers from Bagasse in Whole or Part

Place made	Kind of paper	Run no.	Furnish, %			Physical characteristics																Caliper, 0.001 in.
			Bagasse	Wood sulphite	Groundwood	Basis weight, 25 × 40—500 lb.	Bursting strength, pt./ream-lb. × 100	Tensile strength, kg.—15 mm. width MD	Tensile strength, kg.—15 mm. width CD	Tearing resistance, g. MD	Tearing resistance, g. CD	Folding endurance, Schopper MD	Folding endurance, Schopper CD	Density, g./cc.								
USDA-FPL, Madison, Wis.	Bond	MR-3648	50	50	..	56.9	56.1	9.7	3.4	53.1	64.0	440	45	0.81	3.9							
	Magazine-Book	MR-3649	25	15	60	39.2	33.9	4.6	2.2	25.6	30.1	16	4	0.54	4.0							
	Printing	MR-3590	100	..	..	41.7	75.8	7.6	4.2	22.4	22.4	330	150	0.85	2.7							
	Printing	MR-3591	100	..	25% clay	43.7	38.4	4.9	2.3	24.3	28.8	36	9	0.81	3.0							
Peru	Printing	...	100	..	..	40.0	32.0	3.3	2.3	21.2	25.6	9	6	0.67	3.3							

Worth Checking



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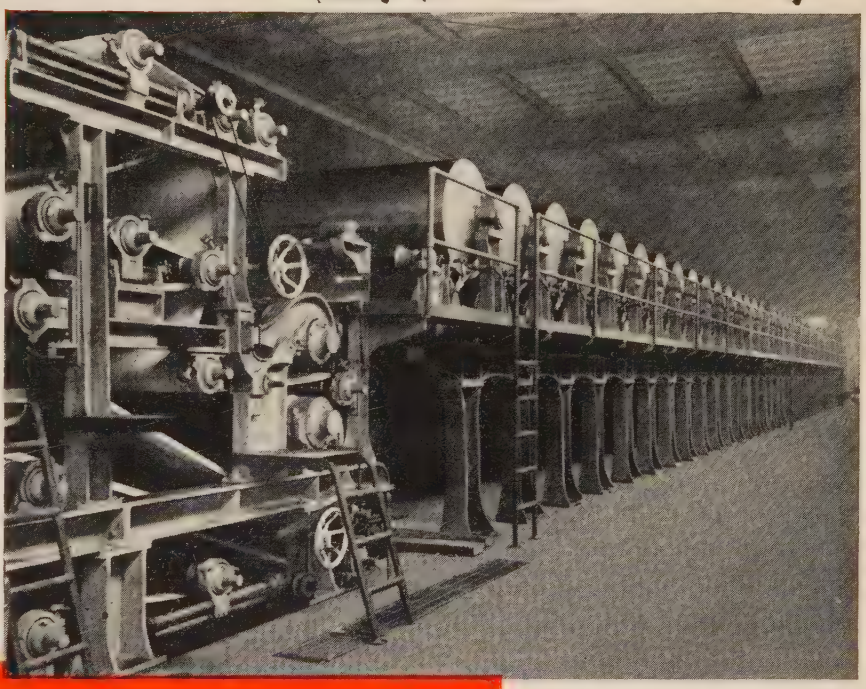
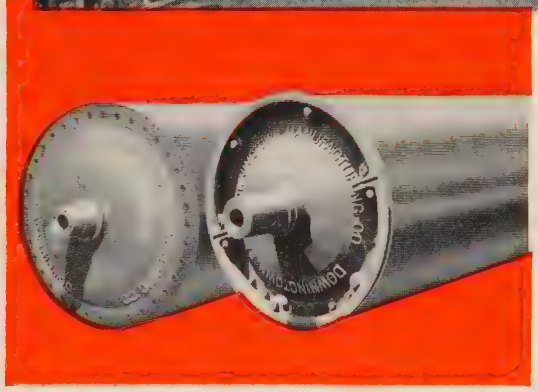


Two deck dryer section in a recently installed board mill. (Note Downingtown "Easy Access" framing.)



The Downingtown Dryer Roll at left has recessed studs in the heads. The one at right is provided with a rope carrier.

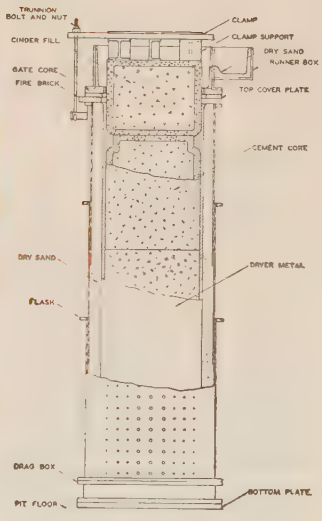


Diagram of Downingtown's Bonded Cement Core Method of molding.

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possible to manufacture usable papers or boards from pulps made from whole or screened bagasse but these will be of low quality. Pulps made by cooking with lime will be useful only in making low-quality board or wrappings. Waste papers if available can be used to advantage in the manufacture of such products.

By pulping with the pressure, Celdecor, or M-C processes, using chemicals composed of or containing caustic soda, much higher grade products including bleached pulps can be made from whole or screened bagasse. When bagasse pulps and waste papers alone are available, the use of liberal amounts of fillers in making printing and other higher grade papers is advisable. By using such methods, boards as well as printing papers of various quality can be produced which will be acceptable in many markets. Much better results will ensue if mechanical wood pulps or kraft pulps made from tropical or hardwoods are available for blending with the bagasse pulps. In such cases the best use for the bagasse pulps will be as blends with the virgin wood pulps and such waste papers and fillers as may be available. Using various such combinations will make possible the manufacture of a much wider range of fairly good to good papers.

The best results can be expected from pulping only depithed bagasse fiber. If commercial uses for the separated pith, such as for fuel, feed, or paper filler, can be found, the costs of such depithed pulps may be found to be lower than those of pulps made from whole or screened bagasse. Such bagasse pulps can be used solely for the manufacture of the highest quality corrugating board medium and also for the manufacture of glassine and certain kinds of waxing papers. When these unbleached pulps are blended with kraft or sulphite softwood pulps, superior wrappings, bag, and multiwall bag papers and liner boards can be manufactured. When the pulps are bleached and blended with bleached mechanical pulps or bleached chemical wood pulps, a wide variety of very high-quality printing and specialty papers becomes available. These bleached bagasse pulps can replace other chemical pulps in blends with mechanical wood pulps to produce newsprint, magazine-book, coated book, and other papers containing large amounts of mechanical pulps. Furthermore, the high tensile strength of these bagasse pulps when produced by the M-C process suggests that weak mechanical pulps might find a much wider use in the manufacture of good papers.

If it should prove expedient to make newsprint from 100% bagasse pulp and filler, a collateral market for the use of the bleached pulp in printing, writing, and other papers should be rapidly developed to provide for the loss of the newsprint market in the event that mechanical pulp or lower cost imported newsprint becomes available.

In selecting pulping methods, consideration should be given not only to the cost elements, such as low initial capital investment, maintenance, and operating costs, but also to simplicity and utility of equipment, flexibility of changing processing conditions to meet changing pulp requirements, and ease of process control. Bagasse is a variable raw material; the paper and board industry in any country is bound to expand with time; and competition in world markets will increase. It is desirable and should be possible to design new mills with great flexibility so as not only to manufacture from the bagasse and other raw materials available in the local market the best products possible but also to provide increasingly better products and products of wider use as the market expands or as other types of pulps and raw materials become available for blending with the bagasse pulps.

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Presented at the ECLA/FAO/TAA Latin American Pulp and Paper Meeting, Buenos Aires, Argentina, Oct. 18–Nov. 2, 1954.

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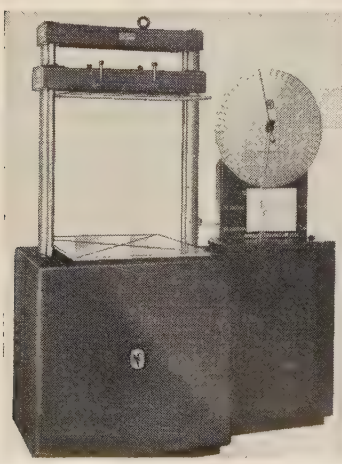

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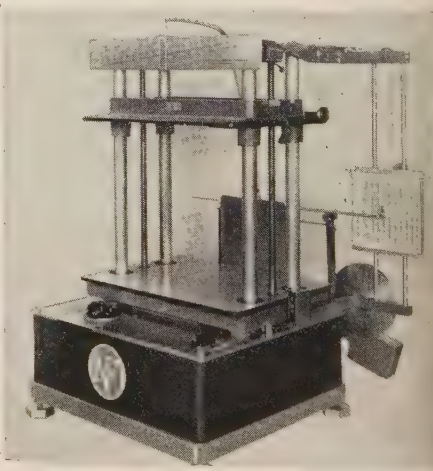

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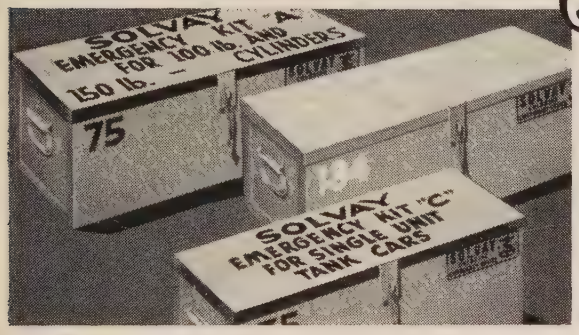

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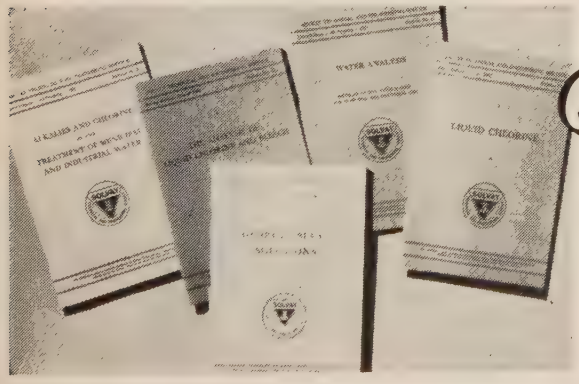

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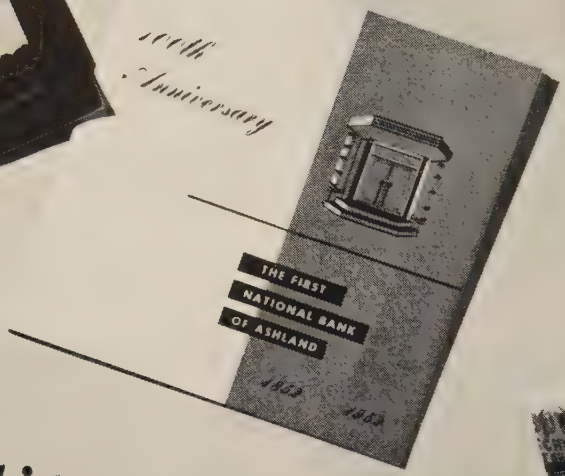

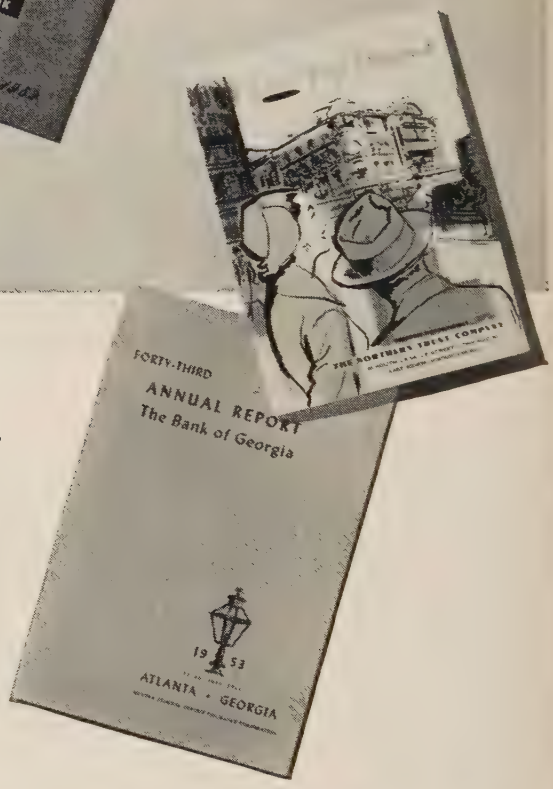

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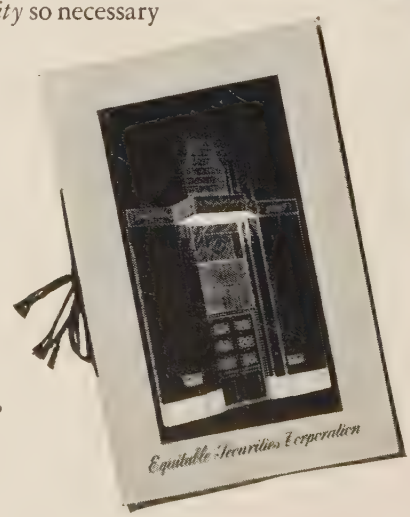

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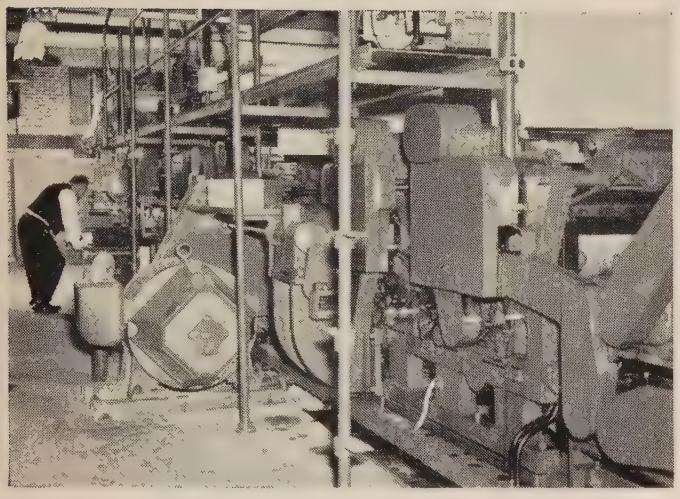

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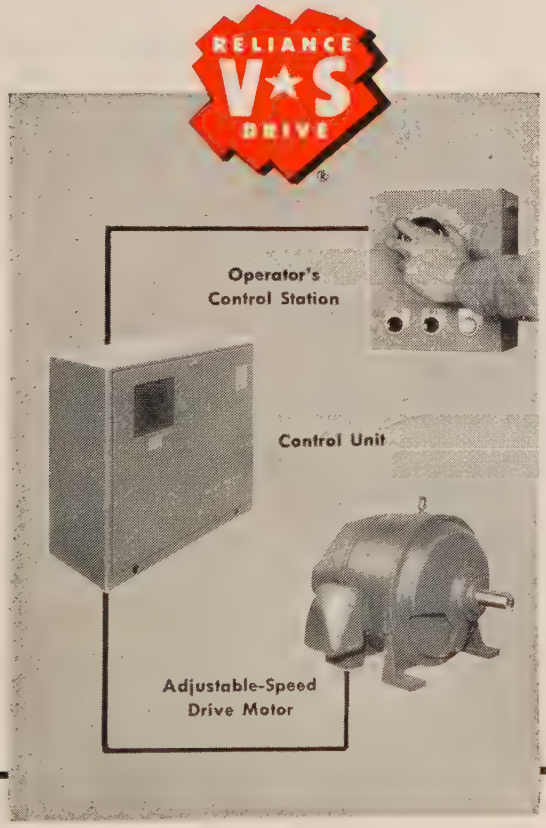

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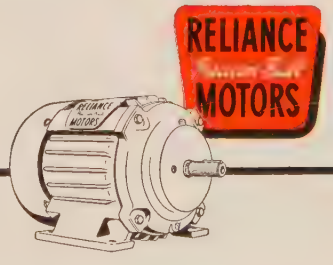

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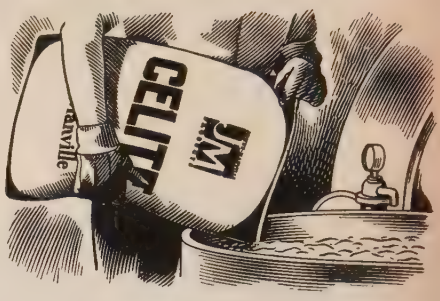

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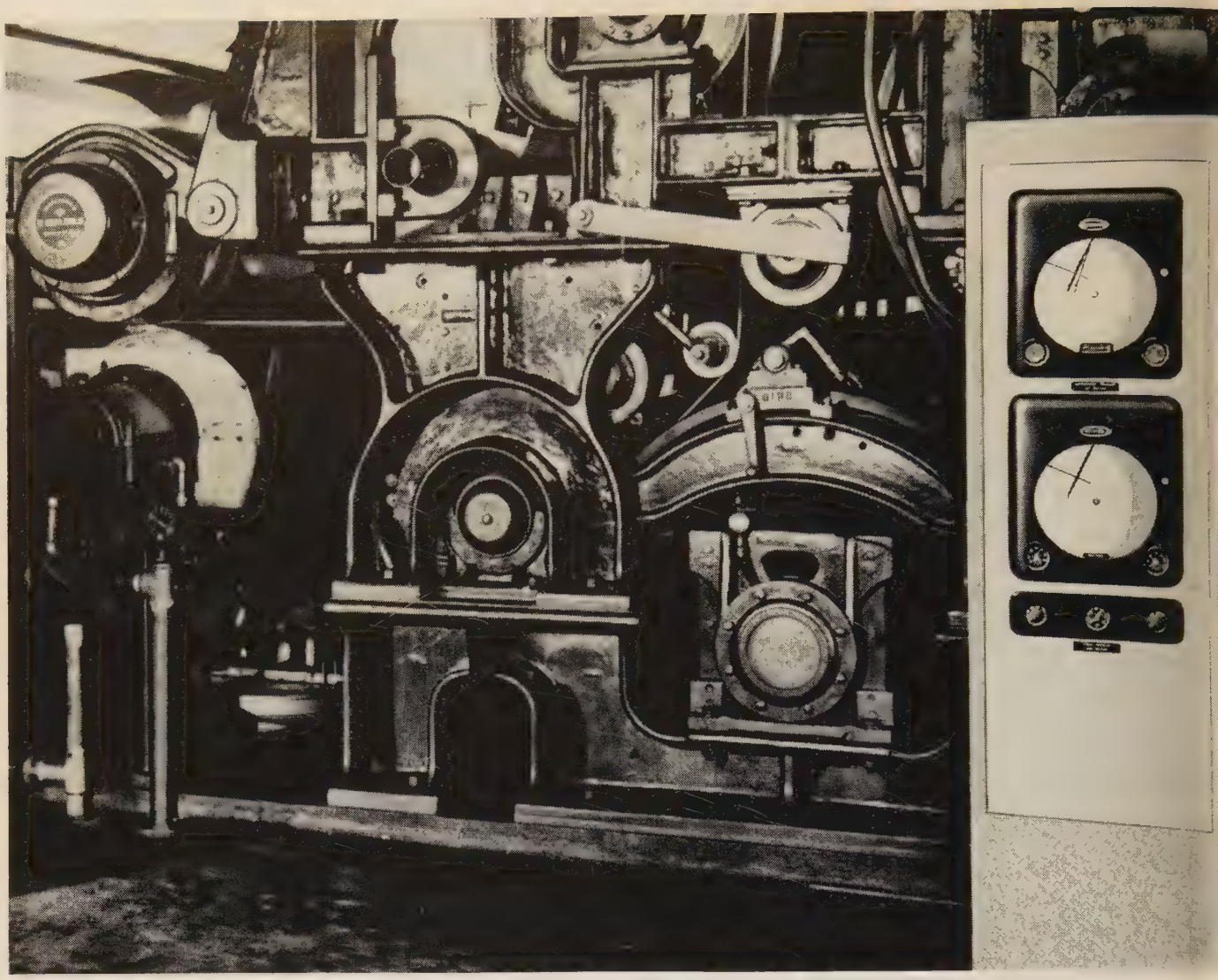

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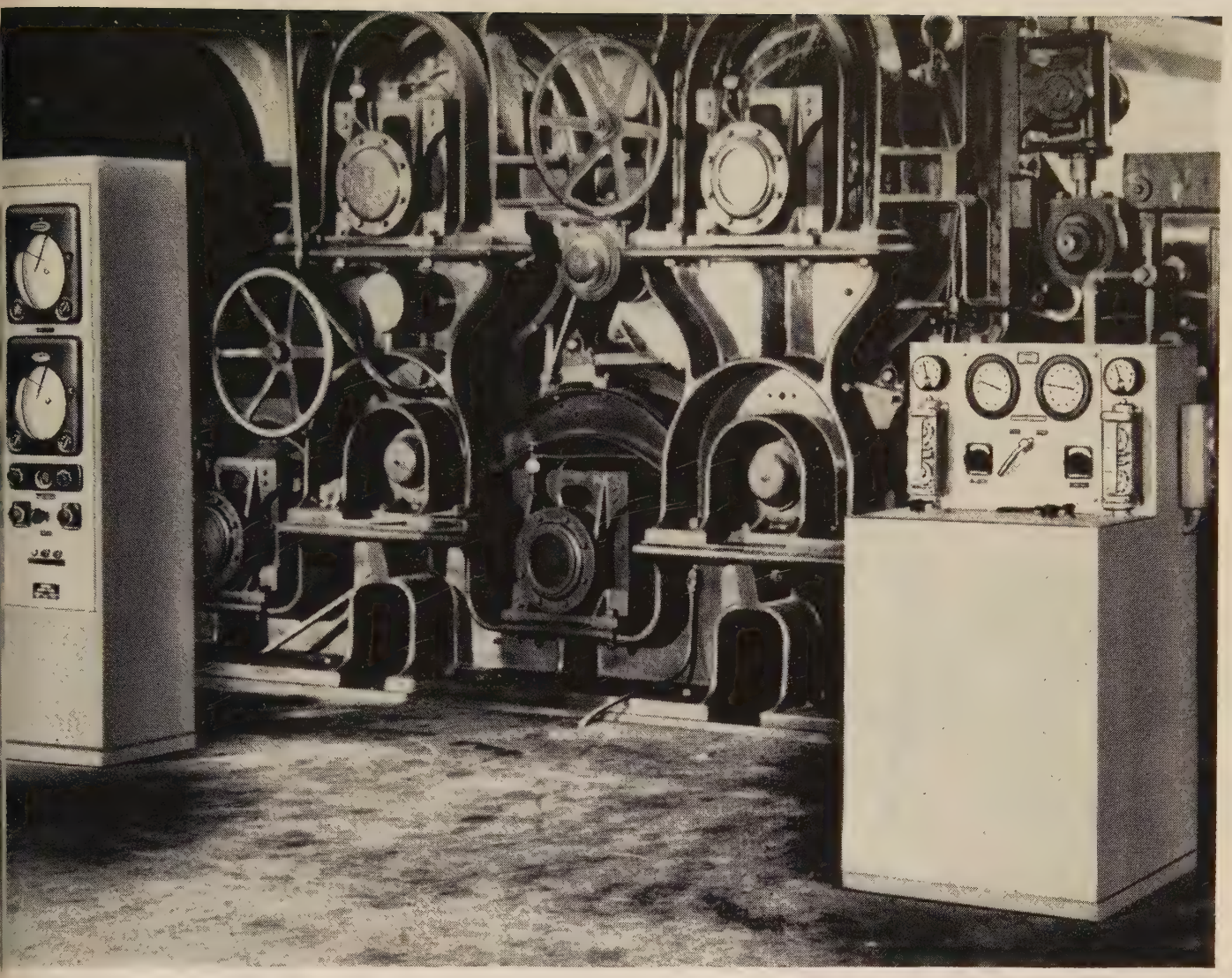

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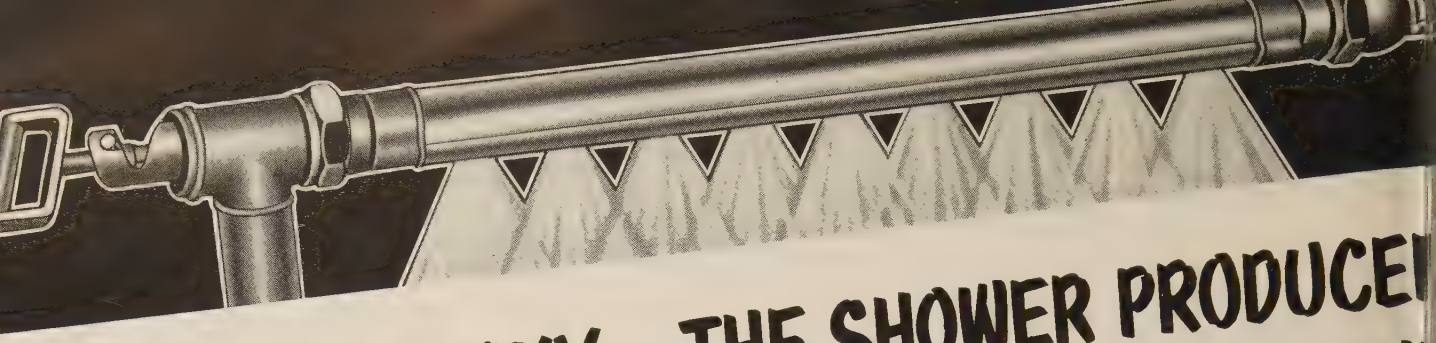

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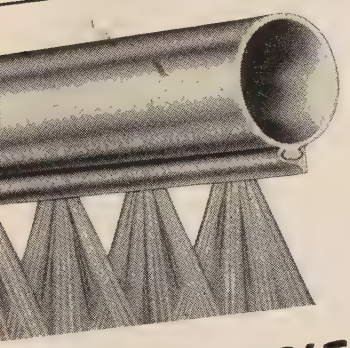

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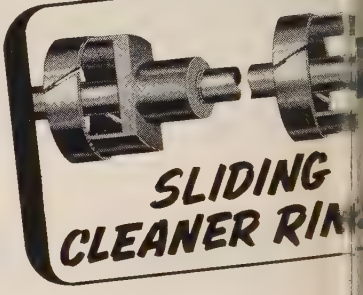
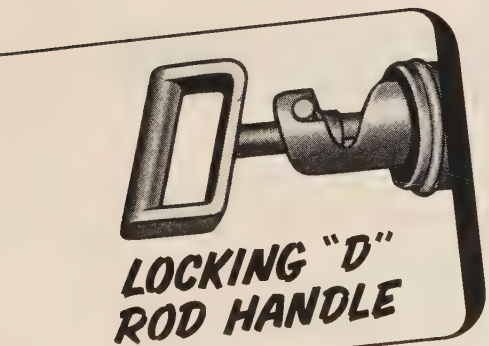
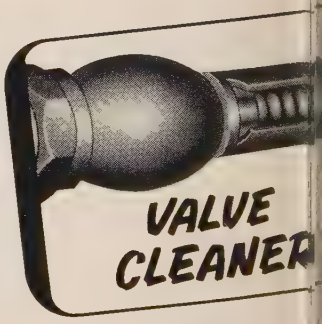


SLIDING CLEANER RIN



LOCKING "D" ROD HANDLE

High on the list would be shower formation—a knife-edged curtain of water with vigorous, effective cleansing action—as supplied by the exclusive Sandusky moveable spray lip.



VALVE CLEANER

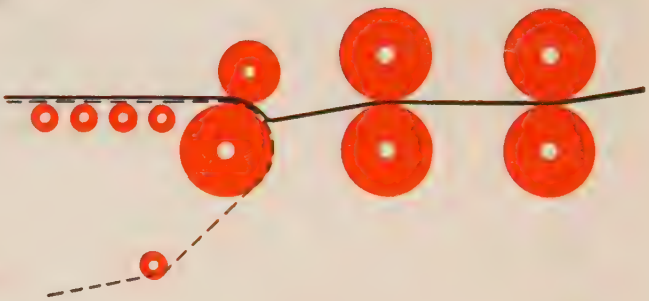
Add the list and you have specified Chief Sandusky. No wonder, for over 40 years paper mill engineers have looked to Chief Sandusky for continuing leadership in top shower pipe performance.

Write or call for further information on easily installed, low maintenance Chief Sandusky Shower Pipes.

SANDUSKY FOUNDRY a MACHINE C
SANDUSKY, OHIO, U. S.

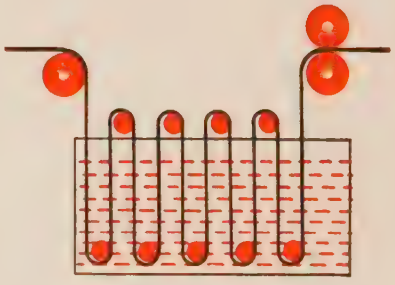
MANHATTAN RUBBER COVERED ROLLS

reduce machine downtime



give you

more use per dollar



Cracking, hardening, corrugation, or separation of rubber from the metal roll core all spell "trouble" for rubber roll coverings . . . and losses in production, quality and schedules. Manhattan roll specialists have eliminated these causes of expensive machine downtime to give you "More Use per Dollar" with Manhattan Rubber Covered Rolls. They have developed an inseparable bond of rubber to metal. They custom-tailor rubber roll covering to meet your specific requirements. You get permanent uniform and correct density and uninterrupted high speed production runs under all working conditions. Discuss your operating requirements with an R/M roll engineer.

ROLL COVERING PLANTS AT PASSAIC, N. J. — NEENAH, WIS. — NORTH CHARLESTON, S. C.

MANHATTAN RUBBER DIVISION — PASSAIC, NEW JERSEY

RAYBESTOS-MANHATTAN, INC.

Other R/M products include: Industrial Rubber • Fan Belts • Radiator Hose • Brake Linings • Brake Blocks • Clutch Facings
Asbestos Textiles • Packings • Engineered Plastic, and Sintered Metal Products • Bowling Balls

RM 421

That's the new, easy way to add high-brightness Dicalite paper-aids. For Dicalite BP-3 and BP-5 are now packed in bags of bleached white sulphate, with no colored stock, no string stitching . . . even the small label is printed in water-soluble ink. With practically a single motion you add paper-aid and pulp at the same instant; no lost time, no spillage to sweep up, no empty bags to pick up and dispose of. (You should slash the bag two or three times before dropping it in the beater.)

This time-saving packaging is just one of many reasons why paper-makers are using more and more Dicalite. The other reasons are fully detailed in our Technical Service Bulletin F-52: among them might be mentioned better pitch, wax and asphalt control; increased board liner coverage; better sheet formation, with increased brightness, opacity and bulking; increased machine speeds through faster drainage and drying, and worthwhile savings in pulp and titanium.

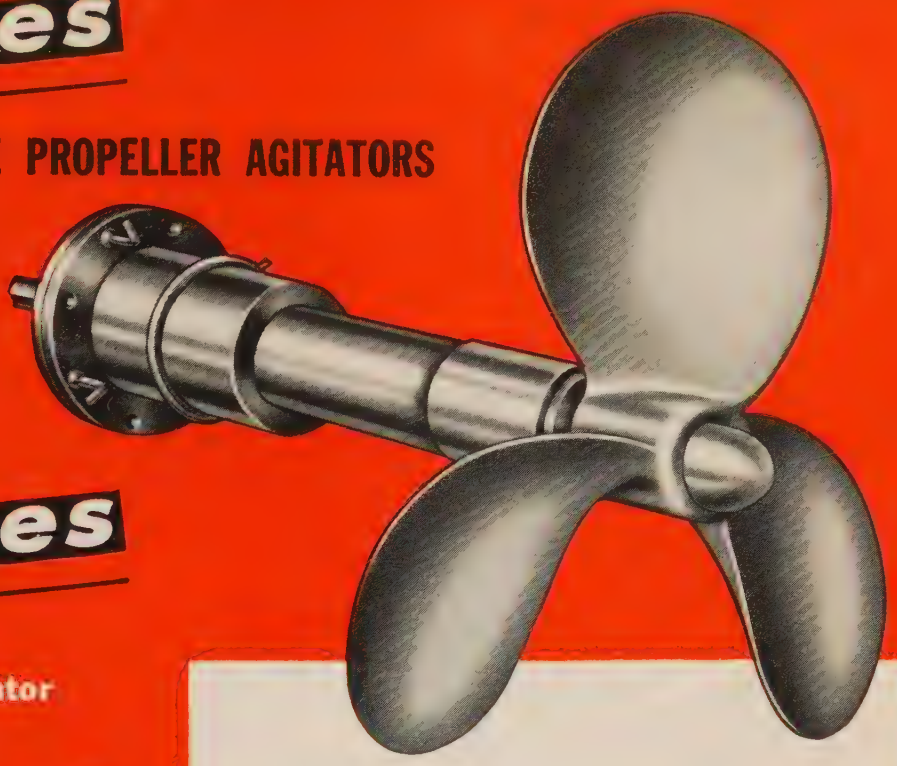
If you haven't a copy of our Bulletin F-52, write in now for your copy. It tells how successful paper-makers in all parts of the country are employing Dicalite paper-aids to speed up production, improve products and cut costs. Some of their methods might be put to work in your own plant.

DICALITE DIVISION, GREAT LAKES
CARBON CORP., 614 SO. FLOWER ST.
LOS ANGELES 17, CALIFORNIA

Dependable GLC GREAT LAKES Dicalite®
DIATOMACEOUS MATERIALS

E.D. Jones

CARTRIDGE-TYPE PROPELLER AGITATORS



E.D. Jones

Fixed Pitch
Propeller Agitator

E.D. Jones

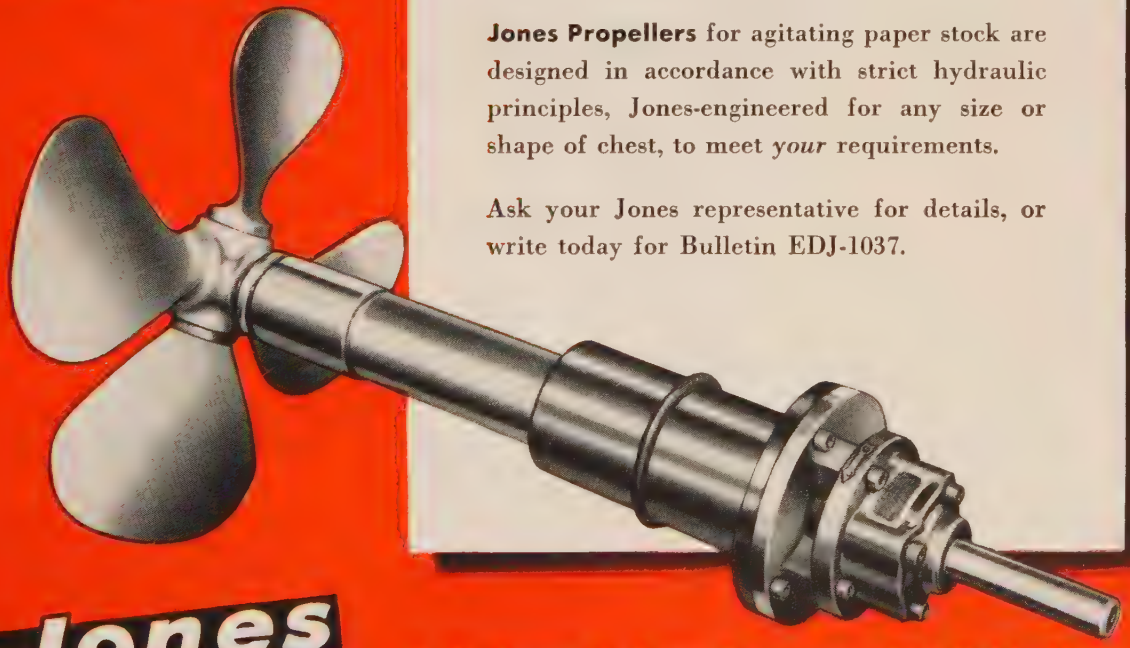
Variable Pitch
Propeller Agitator

Are you plagued by Jordan, Beater or Paper Machine problems caused by inadequate agitation . . . ?

Need better mixing for color blending or to prevent stock stratification . . . ?

Jones Propellers for agitating paper stock are designed in accordance with strict hydraulic principles, Jones-engineered for any size or shape of chest, to meet *your* requirements.

Ask your Jones representative for details, or write today for Bulletin EDJ-1037.

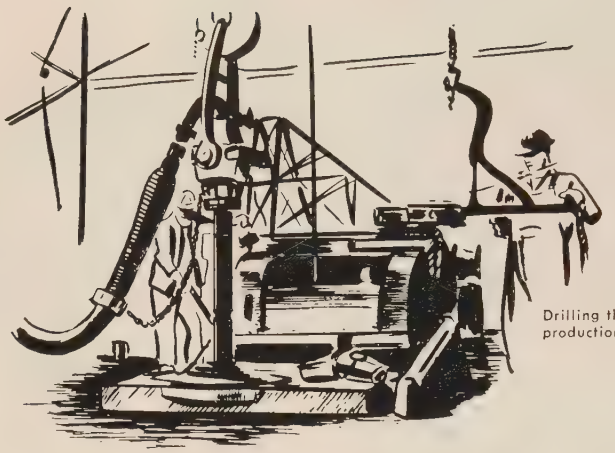


E.D. Jones

E. D. Jones & Sons Company, Pittsfield, Mass.

BUILDERS OF QUALITY STOCK PREPARATION MACHINERY

In Canada: The Alexander Flock Limited, Ottawa



Drilling the production wells

Crude Sulphur

for Industrial Use

from the properties of

Texas Gulf Sulphur Co.

75 East 45th Street • New York 17, N. Y.

Producing Units

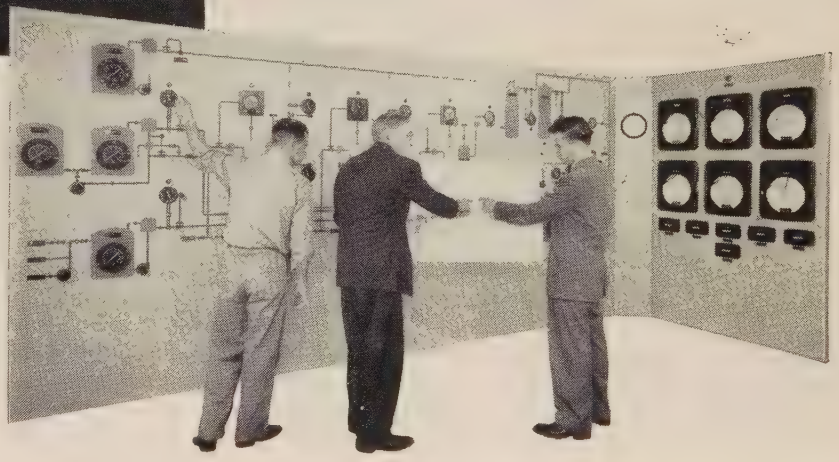
- NEWGULF, TEXAS
- MOSS BLUFF, TEXAS
- SPINDLETOP, TEXAS
- WORLAND, WYOMING

Mark of the Modern Mill . . .

process control

engineered and supplied

by FOXBORO



Why have the great majority of new and modernized mills turned to Foxboro to engineer and supply complete process control instrumentation?

The answer is the leadership which Foxboro has earned throughout the pulp and paper industry . . . leadership in knowledge of the industry's needs, in research, in application experience, in product quality and diversity . . . and in thoroughness of engineering.

In the laboratories and on the drawing boards at Foxboro, today, are tomorrow's control developments for the pulp and paper industry . . . developments that will continue the Foxboro tradition of originating new and better ways to cut production costs and improve product quality.

The Foxboro Company,
7812 Neponset Ave.,
Foxboro, Mass., U.S.A.

Typical Mills with Foxboro Process Control Throughout

*Rayonier, Inc.
Jesup, Ga.
*Buckeye Cellulose Corp.
Foley, Fla.
*Rome Kraft Co.
Rome, Ga.
*Bowaters Southern Paper Corp.
Calhoun, Tenn.
*Ketchikan Pulp Co.
Ward Cove, Alaska
Riegel Carolina Corp.
Acme, N. C.

*Under construction

Brown Co.
Berlin, N. H.
Southern Paperboard Corp.
Port Wentworth, Ga.
Macon Kraft Company
Macon, Ga.
Weyerhaeuser, Pulp Div.
Longview, Wash.
Weyerhaeuser, Pulp Div.
Springfield, Ore.
Marathon Paper Mills of Canada, Ltd.
Marathon, Ont.

Long-Lac Pulp & Paper Co., Ltd.
Terrace Bay, Ont.
Columbia Cellulose Co., Ltd.
Watson Island, B. C.
Sorg Pulp Co., Ltd.
Port Mellon, B. C.
St. Lawrence Corp., Ltd.
Red Rock, Ont.
Fraser Companies, Ltd.,
Newcastle, N. B.
MacMillan and Bloedel, Ltd.,
Harmac Div.
Nanaimo, B. C.

FOXBORO
Reg. U.S. Pat. Off.

PULP and PAPER MILL INSTRUMENTATION

FACTORIES IN THE UNITED STATES, CANADA AND ENGLAND

"VIRGINIA" ZINC HYDRO

cuts groundwood bleaching costs 50%
increases brightness 12 points

That's the kind of brightening job "Virginia" can do on your groundwood pulp. That's the kind of savings which use of our reducing agent puts in your pocket.

Some mills have gained as much as 13 points, at one-third the cost of oxidizing bleaches. Saving: a cool $8 per ton. Bleaching with our zinc hydro can be done for as little as 60c per brightness-point per ton. And brightening is *permanent*—there is no reversion of color.

Low-cost "Virginia" Zinc Hydro is non-corrosive, stable in storage, easy to use in the plant. No expensive special equipment is needed. Many auxiliary chemicals are eliminated. "Virginia" Zinc Hydro works just as well in a small, non-integrated mill as it does in a large, continuous-production groundwood operation.

Call on us for proof of all this. The technical and practical knowhow of our experts is at your disposal. Write us today.

Industrial Department
VIRGINIA SMELTING COMPANY
Dept. 77-P, West Norfolk, Virginia

VIRGINIA Chemicals

Field Offices: NEW YORK • BOSTON • DETROIT
CHICAGO • ATLANTA • ASHEVILLE
Available in Canada and many other countries

Regulate Surface Density

KELSIZE and KELGIN

Control surface density by applying a 0.20% to 3.5% solution of KELSIZE or one of the KELGINS at calender stack or size press.

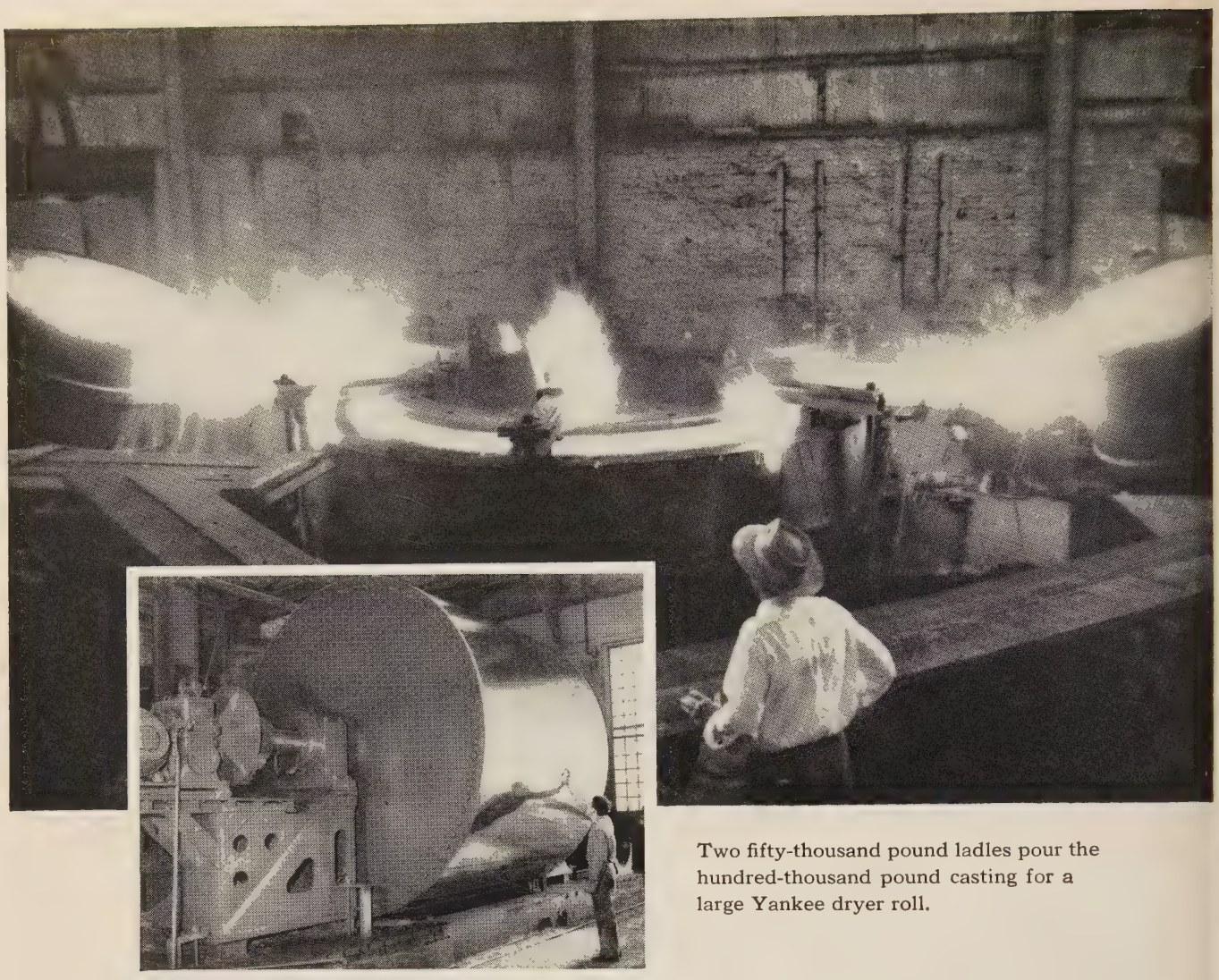
You secure all four of these outstanding advantages:

1. Improved smoothness and finish
2. More uniform printing surface
3. Greater wax, oil and varnish resistance
4. Better coating surface

Contact our nearest regional office for technical service regarding your sizing problems.

KELSIZE® and **KELGIN®**. . . products of **KELCO** company
31 Nassau Street, New York 5, N. Y.
20 N. Wacker Drive, Chicago 6, Ill.
530 W. Sixth Street, Los Angeles 14, Calif.
Cable Address: Kelcoalgin — New York

Picture of "Vanceometer" Oil Absorption Tester courtesy of Hillside Laboratory Hillside, Ill.



Two fifty-thousand pound ladles pour the hundred-thousand pound casting for a large Yankee dryer roll.

Where

Yankee Dryer Rolls...and paper quality... get started right

Here in this foundry is where many a paper mill's *quality control* begins.

Here is where strength is born to provide steam-tight dryer rolls. And here, too, the fine grain of the metal is assured. That is important, as you know, since the finer the grain the higher the polish.

As you see from the small illustration, the Newport News Yankee dryer roll takes a mirror-like finish.

Newport News has equipment for casting and machining paper mill rolls up to 12 ft. in diameter, and to 320 inches in length. Output is numbered in the hundreds. And deliveries are prompt. Your inquiries are invited.

NEWPORT NEWS
Shipbuilding and Dry Dock Company
Newport News, Virginia

No other single source offers such a complete line of top-quality paper chemicals...all quality-controlled...to meet your specific mill needs

ACCO* Gum Rosin Sizes, liquid and dry

ACCOBRITE® Rosin Sizes, liquid and dry

AEROSIZE® High Free-Rosin Emulsions, two grades

CYFOR® Fortified Sizes, liquid and dry

CYRON* Synthetic Size — highly effective in acid and alkaline stocks — can be used on the surface or added to stock

DARK WOOD ROSIN SIZES — several grades, liquid and dry

ALWAX* and WAXINE® Wax Sizes — various grades to suit individual requirements

ALUM — Commercial and Iron-Free grades, liquid and dry

SODIUM PHOSPHO ALUMINATE — for improved sizing, retention of fines, and control of acidity

MELOSTRENGTH® and PAREZ® Synthetic Resins — melamine and urea resins for improved wet and dry strength and other effects

ACCOCEL® Pitch Dispersant

AZITE® 900 Liquefier — for viscosity control of starch, glue and casein solutions

CYNOL® Defoaming, Rewetting and Softening Agents

Acids and Alkalis

Formaldehyde — Silicate of Soda

AEROSOL® Surface Active Agents — CALMICRO® Calcium Carbonate

Boston • Charlotte • Chicago • Cincinnati • Cleveland • Detroit • Houston • Kalamazoo • Los Angeles • Mobile • New York • Oakland • Philadelphia Portland, Ore. • St. Louis • Seattle • Waterbury

*Trade-mark

In Canada: North American Cyanamid Limited, Toronto and Montreal

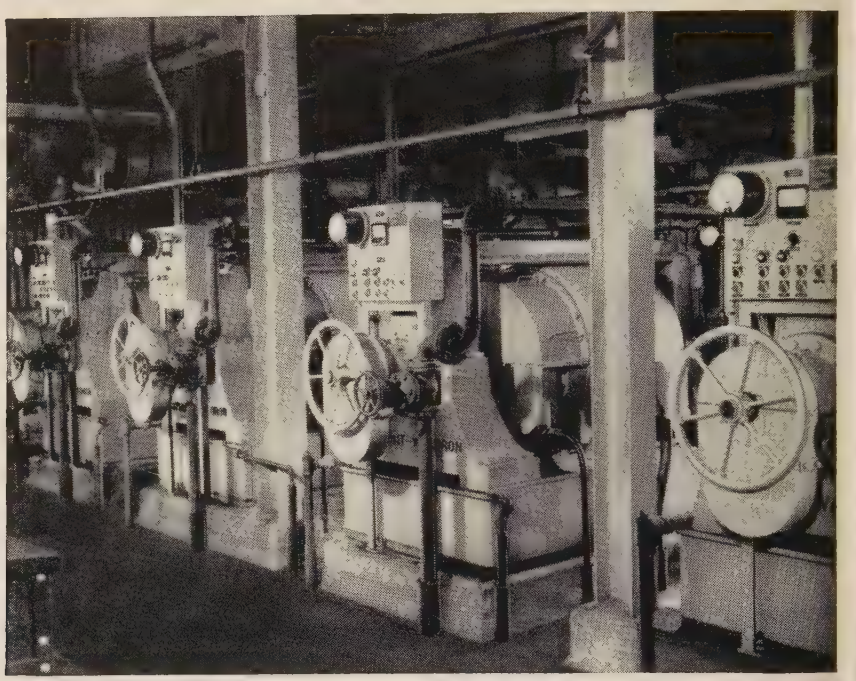
for economical SEMI-CHEMICAL *pulping*

AMERICAN BOX BOARD COMPANY

continually chooses

SPROUT-WALDRON

36-2 REFINERS



Four of the eight Sprout-Waldron 36-2 refiners at American Box Board Company, Filer City, Michigan. All eight units refine neutral semi-chemical chips for 9 point corrugating board in this most modern semi-chemical mill. Two were installed in 1948, one in 1949, four in 1952 and one in 1954. Repeat orders, such as this, are the best evidence of customers' satisfaction with Sprout-Waldron Refiners.

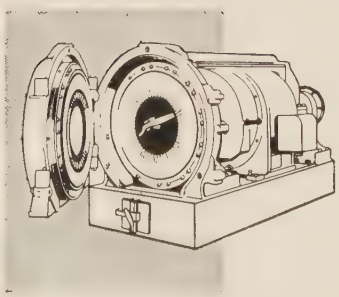
The SPROUT-WALDRON refiner is the leading producer of semi-chemical pulp

Single disc design, peripheral control ring and rugged construction for...

- **high pulp quality**
- **high capacity**
- **flexibility of operation**
- **low maintenance**

For more information on semi-chemical pulping, or any other pulping application, send for our file of technical and practical data. Write to Sprout-Waldron & Co., Inc., 38 Logan Street, Muncy, Pa.

S W

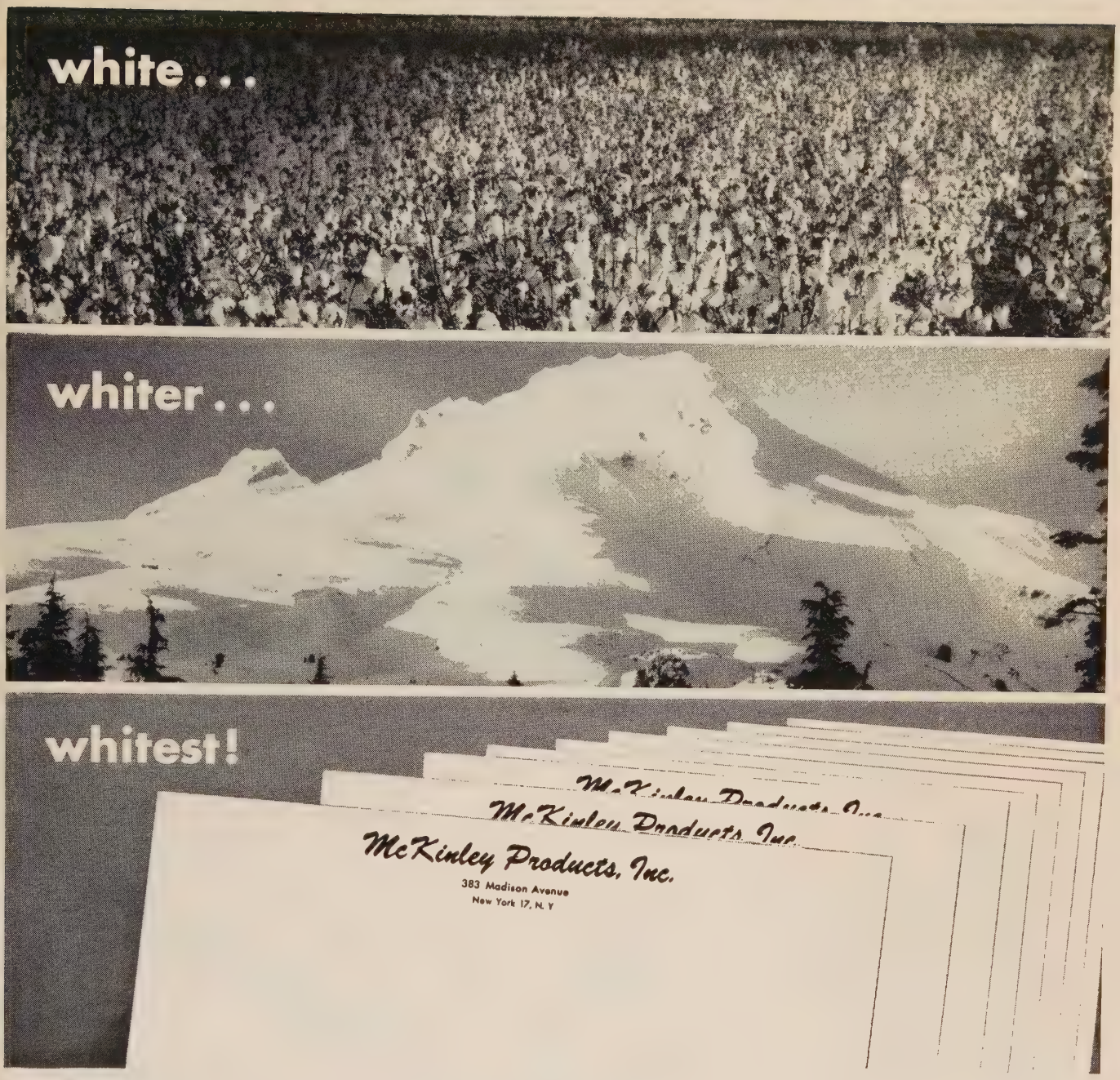


for your pulping problem—

SPROUT-WALDRON

PULP REFINERS

361



NEW Du Pont Paper White BN will make your paper whiter than words — or pictures — can say

You'll have to see it to believe it—a dye that makes paper so white that most of today's papers look dull and gray by comparison!

White as a field of cotton at picking time? No. There never was a cotton boll *this* white.

White as new-fallen snow? Frankly, that doesn't describe it either. The only way you can see just how white paper can be is to send in the coupon below for a sample of paper dyed with new Du Pont Paper White BN.

DU PONT
REG. U. S. PAT. OFF

Du Pont Dyes

BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY*

Fill in This Coupon and Mail Today for Samples

E. I. du Pont de Nemours & Co. (Inc.)
Dyes and Chemicals Division—N-11496
Wilmington 98, Delaware

Gentlemen:

Please send me samples of paper dyed white with new Du Pont Paper White BN.

NAME_____ TITLE_____

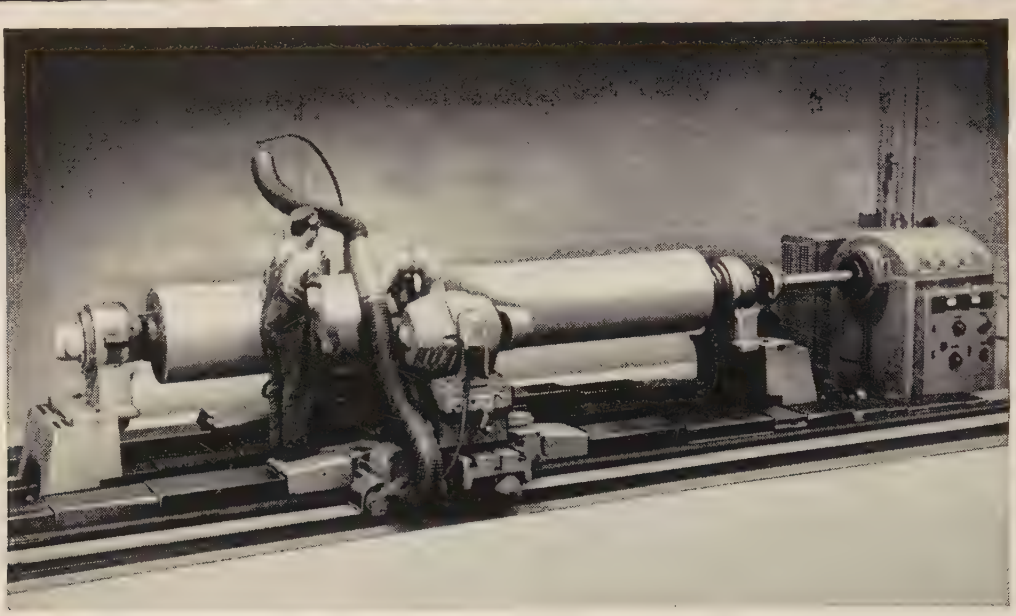
FIRM_____

ADDRESS_____

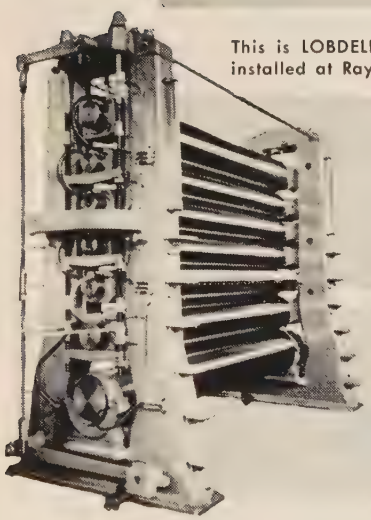
CITY_____ STATE_____

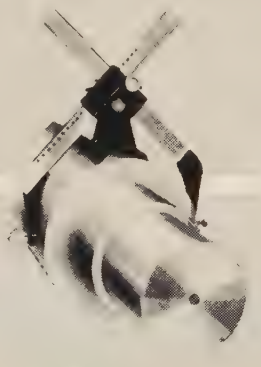
LOBDELL

SPECIALISTS TO THE PAPER INDUSTRY FOR 72 YEARS



This is LOBDELL's big 60" capacity Type CW Roll Grinder (Can handle 60" x 338" roll) installed at Raybestos—Manhattan's new rubber covering plant, Neenah, Wisconsin.





Pioneers in the production of Chilled Iron Rolls, LOBDELL has for 72 years served the Paper Industry with the finest in Rolls, Calender Stacks, Roll Grinders and Roll Calipers.

ROLLS—Plain Chilled Iron have uniformly hard surface, highly resistant to abrasion and deformation under load.

Alloy Chilled Iron for water finish or high pressure stacks . . .

MACHINE CALENDER STACKS—for all services.

MICROMETER ROLL CALIPERS—light weight permits easy handling by one man, and are readily adjusted to wide range of roll diameters.

ROLL GRINDERS—Rugged, extremely accurate, with ease and flexibility of operation; in full range of sizes for all mill requirements. Three basic sizes designated for alternating current drives, varying in sizes according to roll diameter, length and weight; two larger sizes designated for direct current drives; and for maximum roll diameters of 48" or 60", weighing 40 or more tons.

KNIFE GRINDERS—Bridgeport's heavy duty knife grinders—top grinding efficiency for today's multi-knife chippers.

ABRASIVE CUT-OFF SAWS—"Abrasaw" heavy duty cutoff saws —Fast, serviceable, accurate for pipe, small shapes and bars.

1836

LOBDELL UNITED COMPANY

WILMINGTON 99, DELAWARE

A SUBSIDIARY OF UNITED ENGINEERING AND FOUNDRY COMPANY

1954

Over 750 Installations
in 22 Countries
Throughout the World

Morden-ize

THE 3 BASIC TREATMENTS IN YOUR STOCK PREPARATION

EACH STOCK requires one or more of these basic treatments.

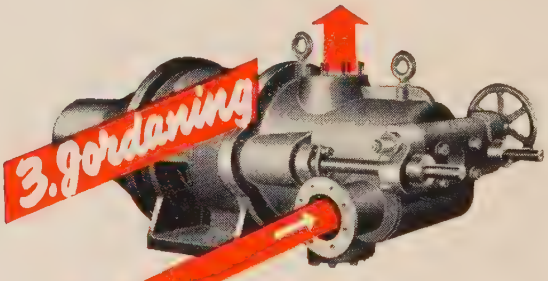
EACH MORDEN MACHINE is engineered, standardized and proven in one of these basic treatments.

EACH MILL'S requirements suggest various applications.

OUR EXPERIENCE in assisting mills to develop simple, effective and economical stock preparation systems is available to you upon request.

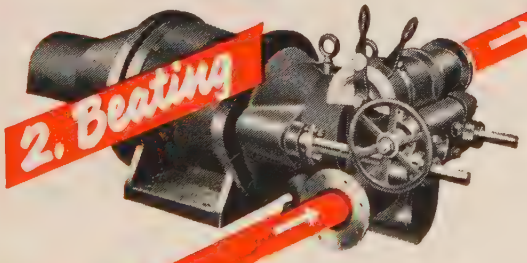
MORDEN SLUSH MAKER®

...for completely defibering all pulps, papers and brokes (even wet strength) without auxiliary equipment.



MORDEN STUFF MAKER

... for cutting or shortening where required to obtain specific sheet properties.



MORDEN STOCK MAKER®

...for brushing, fibrillating and hydrating individual fibers for maximum strength development.

MORDEN
STOCK PREPARATION EQUIPMENT
MACHINES COMPANY

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Northeastern States Representatives:
ORTON CORPORATION, Fitchburg, Massachusetts

Midwestern States Representatives:
DAN B. CHAPMAN, Appleton, Wisconsin

Other Representatives in most paper-making countries.

MORE NEW
PENFORD GUMS
FOR THE
PAPER INDUSTRY

New Penford Gums are now available to complement the standard series of Penford Gums already in general use throughout the paper industry. This makes available to the paper industry, for the first time in commercial quantities, starch hydroxy ethyl ethers, covering the complete range of viscosities—from the thickest starches to the thinnest dextrines.

The new Penford Gums are more reactive with synthetic resins, exhibit less tendency to set back or gel and are more resistant to spoilage. The films of Penford Gums are clearer, stronger, more flexible, and more grease resistant.

Various Penford Gums are commercially available, having gelatinization or swelling temperatures covering the range from 130°F to 185°F.

Penford Gums are used as wet end additives for improvement in Mullen and stiffness.

The appropriate Penford Gums, when used for surface sizing, will impart improved strength characteristics such as pick, Mullen, and tensile. In addition, smoothness and printability can be greatly increased.

Penford Gums are also in general use for size press coating and conventional machine and off-machine coating. By using the appropriate Penford Gum, a complete range of coating weights may be applied to get the required coating properties.

Please write or call for technical service and data for specific mill applications.

PENICK & FORD, LTD., Incorporated

420 Lexington Avenue, New York City **Cedar Rapids, Iowa**

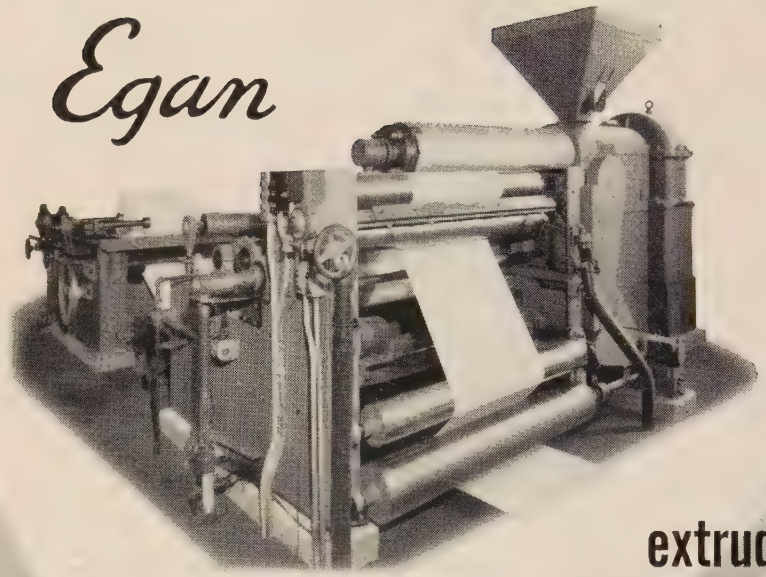
Penford Gums are Starch Hydroxy Ethyl Ethers manufactured under U. S. Patents #2,516,632, #2,516,633 and #2,516,634.

Christmas 1954

ALL OF US
WHO HAVE HAD THE PLEASURE
OF SERVING YOU THROUGHOUT
THE YEAR . . .
JOIN IN WISHING YOU
A VERY MERRY CHRISTMAS
AND ALL THE BEST IN 1955

The Officers and Employees of the
LOCKPORT FELT COMPANY
NEWFANE, NEW YORK

Egan



polyethylene extruder-laminator

(Above pictured installation at the Milford, N. J. plant of RIEGEL PAPER CORPORATION)

COMPLETE PACKAGED MACHINE

Combining in one unit, in engineered balance, two famous units—The Egan Extruder and the Egan Laminator. Planned for your current—or expanding—production, available in varying sizes—from 24″ Pilot Plant Size to 96″, 1000 feet per minute continuous operation. Machines are capable of coating on paper and paperboard, cellophane, foil, glassine and cloth.

30 **Egan machines now in operation.**

5 **Egan machines under construction.**
Approximately 75% of all polyethylene extruder-laminating machines now in operation anywhere in the world are Egan Equipment.

FRANK W. EGAN & COMPANY, Bound Brook, New Jersey

Designers and Builders of Machinery for the Paper Converting and Plastics Industries

Cable Address: "EGANCO"— Bound Brook, N. J.

Representatives: WEST COAST — John V. Roslund, 244 Pacific Bldg., Portland, Ore.
MEXICO, D. F. — M. H. Gottfried, Avenida 16 De Septiembre, No. 10.

Licensees: GREAT BRITAIN — Bone Bros. Ltd., Wembley, Middlesex. FRANCE — Achard-Picard, Remy & Cie, 36 Rue d'Enghien, Paris X^{e}. ITALY — Emanuel & Ing. Leo Campagnano, Via Borromei 1 B/7, Milano.
GERMANY — ER-WE-PA, Erkrath, bei Dusseldorf.

Have you recently re-examined the profit potential in **COLORED LINES?**

Running colored specialty lines need not introduce complications in your mill operations. With proper formulas and operating methods, colored lines are now easy to handle in the mill. And they can add unexpected income compared to the cost of coloring involved.

National Technical Service has helped many mills to produce colored lines efficiently and economically. Our paper technicians can provide low-cost formulas, stock compositions as well as in-the-mill operating help to get you started.

These services supplement our dependable delivery of the dyes you need from nearby warehouse stocks. They make it easy for you to add color lines now.

NATIONAL PAPER DYES

NATIONAL ANILINE DIVISION
ALLIED CHEMICAL & DYE CORPORATION
40 RECTOR STREET, NEW YORK 6, N. Y.

Boston Providence Philadelphia Chicago San Francisco
Portland, Ore. Greensboro Charlotte Richmond Atlanta
Los Angeles Columbus, Ga. New Orleans Chattanooga Toronto

Allied Chemical

growing?

For the wax user whose operation is constantly growing, investigation of the improved line of Cities Service Pacemaker Waxes will prove invaluable. Call or write Cities Service Wax Dept., Sixty Wall Tower, New York 5, New York.

CITIES SERVICE

QUALITY PETROLEUM PRODUCTS

Fiber Properties and Fiber-Water Relationships in Relation to the Strength and Rheology of Wet Webs

L. M. LYNE and W. GALLAY

Previous studies of the structure and properties of wet webs have been continued and extended. The effects of wet pressing and of beating on the strength development curve with increasing dryness have been determined. Per cent voids, i.e., percentages of air by volume in the webs, have been calculated and the importance of voids in relation to surface tension forces discussed. Relationships are shown among per cent voids, tensile strength, density, and per cent solids. Rheological studies have been carried out on wet webs over a wide range of solids contents. A second stress-strain instrument was constructed for applications of heavier loads at higher solids. The wet webs down to about 8% solids show all the usual rheological properties found for dry paper including permanent set, recoverable creep, work hardening, resilience, and memory effect. The results appear to corroborate strongly the concept of two essentially successive mechanisms, viz., surface tension and inter-fiber bonding, governing the strength and other properties of wet webs. These two mechanisms can be clearly distinguished and separated. The structure of wet webs on the basis of these findings is discussed.

THE research reported in this paper deals with a further phase of a general program of investigation on the structure and properties of wet webs, on which two previous communications have been made by the authors (*1*, *2*). These investigations have been undertaken not only with the aim of furthering our knowledge of the structure and properties of wet webs and the fundamental mechanisms entering into their strength development, but also with the aim of arriving at some general unifying concept of structure and behavior covering the range in these webs from earliest formation through to the finished paper.

The strength development investigation in wet webs with increasing solids previously reported (*2*) was carried out with unbeaten pulps and untreated glass fibers using air drying for water removal. It was concluded from this work, that strength development with increasing water removal was attained through two essentially successive mechanisms, the change in the nature of the main operative forces being reflected in a discontinuity in the strength development curve. Up to about 20 to 25% solids (cf. Fig. 1, curve 1, and Fig. 6, curve 1) the strength increases through increasing surface tension forces which show a rapid decrease after the first inflection. Inter-fiber bonding then becomes the major factor in strength development and the strength increases to dryness. A marked discontinuity is noted at about 20 to 25% solids, the shape and magnitude of the inflections being dependent on the nature of the system involved. A sharp demarcation between the two regions is probably not to be assumed. It is far more likely rather that inter-fiber bonding plays a negligible role in strength development at low solids, increases slowly and steadily to the region of the first inflection, and then becomes the major operative force after surface tension has reached its maximum. Similarly, it is probable that surface tension forces continue to contribute to strength after their maximum value has been reached, decreasing, however, to a negligible value at an intermediate stage of dryness.

It was further clearly shown (*2*) that the magnitude of these forces was reflected in the same way by changes in density of the wet web as water was removed by air drying. Dimensional changes in the plane of the test strips were very small with increased drying in the wet web region. Very pronounced changes in thickness of the web were noted, however. As drying proceeded in the earlier stages up to about 25% solids, the thickness decreased steadily as a result of the pulling together of the fibers by surface tension forces. In the case of pulps, a discontinuity in the thickness-solids curve was obtained in the same region of dryness as the discontinuity in the strength development curve. Then with increased effect of bonding on further drying, the thickness continued to decrease. A close relationship was thus shown between strength and density in the wet web.

With webs consisting of glass fibers, where inter-fiber bonding was absent, strength developed to a maximum at about 20 to 25% solids and then decreased sharply to a low value. Here surface tension forces were operative without bonding. The thickness of these webs decreased steadily with increased drying, and then increased sharply at about 20 to 25% solids, showing a minimum in thickness or a maximum in density at the same stage of dryness as the maximum in strength. On the addition of bonding agents, the course of the strength development and of the density curves with increased drying resembled those for pulp. Thus the effect of inter-fiber bonding, absent in these webs without extraneous bonding agents, was clearly distinguished. Again, a close relationship was thus shown between strength and density in these wet webs.

Other evidence was presented (*2*) showing the importance of surface tension forces in wet web structure and properties.

Experimental details of sheetmaking and strength measurments have been previously described (*1*) and only further modifications or additional procedures will be given in the present work.

DENSITY-STRENGTH RELATIONSHIPS

It is emphasized that the previous work was carried out by air drying unbeaten pulps or glass webs. The forces involved were shown to exert a strong pulling to-

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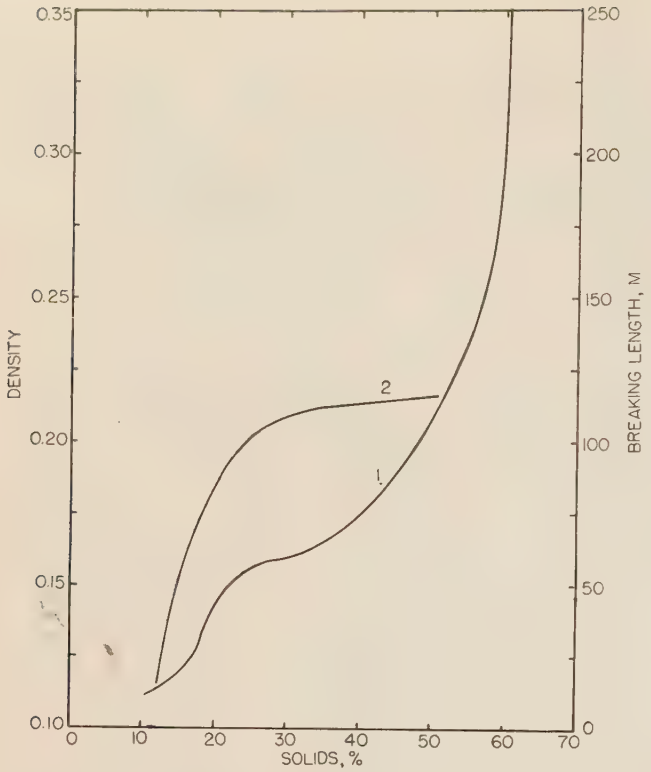

Fig. 1. Strength and density of spruce groundwood wet webs with increasing per cent solids; water removal by air drying

1—tensile strength, and 2—density.

gether of the fibers in the thickness dimension, with only negligible changes in the other two dimensions. This results very probably not only in a further strengthening of the action of surface tension, but also in a bringing together of the fibers into closer juxtaposition to yield conditions more favorable for inter-fiber bonding. Thus it may be considered that the net result of surface tension insofar as dry paper is concerned is the preparation of the web for inter-fiber bonding.

On this basis it was of interest to examine the effects of procedures which would be expected to increase the density of the wet web at early stages of drying. The two most obvious and commonly used procedures in papermaking for this purpose are wet pressing and beating, and each of these was separately examined for its effect on the course of strength development on water removal.

Density in these wet webs is defined in all cases in this work as the ratio of the dry weight of the fibers to the volume occupied by the wet web. Since all of the webs were maintained at constant dry basis weight, the density varies inversely as the caliper.

Wet Pressing

For this work, water removal was effected by pressing between blotters to varying extents. Otherwise the procedures of sheetmaking and strength measurement were identical with those used for the previous work involving water removal by air drying (*1*).

Figure 1 shows the relationships of breaking length and density to per cent solids for a spruce groundwood wet web using air drying for water removal. It is noted that the two curves are similar with an inflection point at about 20 to 25%. Figure 2 shows the corresponding relationships for the groundwood wet web using wet pressing as the means of water removal. It is noted that the inflection points are now essentially absent. Both the strength and density increase continuously without notable discontinuity.

Figure 3 shows changes in strength and density in webs consisting of glass fibers of 2.5 mu diameter, water removal having been carried out by air drying. Pronounced maxima in strength and density are shown at 23 to 25% solids, and the relationship between strength and density may be clearly noted. Figure 4 summarizes similar data for glass fiber webs using fibers of the same average diameter, where water removal had been carried out through the agency of wet pressing. A maximum in strength is obtained at about 25% solids, this strength being lower than that for the air-drying webs as a result presumably of some crushing and hence shortening of the fibers. The density, however, shows an initial rise followed by an essentially constant value.

It has been previously noted that the increasing density brought about by surface tension forces may be logically assumed to assist greatly in bringing into play inter-fiber bonding in the wet pulp webs. Wet pressing obviously brings about a reduction in caliper and an increase in density through the pressing action aside from water removal. It may therefore be further considered that inter-fiber bonding will be greater at a given solids content in this early region than with air-drying webs. Thus the enhanced effect on surface tension and the earlier development of inter-fiber bonding would result in a smooth merging of the decline in sur-

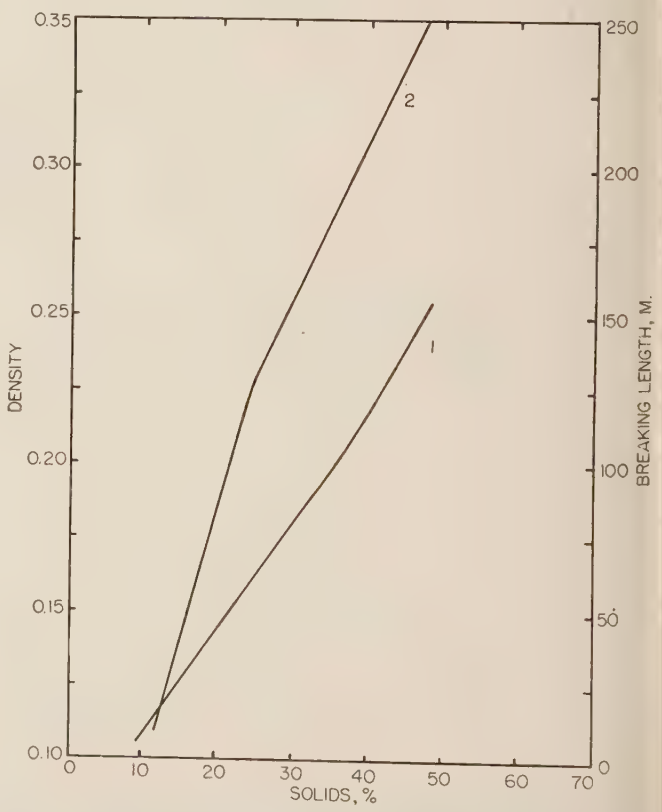

Fig. 2. Strength and density of spruce groundwood wet webs with increasing per cent solids; water removal by wet pressing

1—tensile strength, and 2—density.

face tension and strong increase in bonding at about 20 to 25% solids, and no discontinuity would be evident. With glass fiber webs, surface tension forces show a maximum regardless of the method of water removal, since no subsequent inter-fiber bonding is possible. It is noted with wet pressing that the density no longer shows a maximum similar to the strength development. An initial compacting only is possible, following which the density remains essentially constant at a level slightly higher than the maximum density obtained in the air-drying webs, as a result of the mechanical breakage of fibers in the system with increased degree of pressing.

Beating

It need hardly be noted that concepts of the basic effects of beating of pulp fibers insofar as dry strength development is concerned are still somewhat obscure. It is well known, however, that there is a definite relationship between beating and increased density of the dried sheet. It has been proposed (*3*) that the most important effect of beating is the increased degree of swelling of the fibers resulting in decreased elasticity and increased plasticity. On this basis it may be assumed that inter-fiber bonding would be increased in the very wet web and the shrinkage in thickness is then greater on subsequent drying resulting eventually in a greater density in the dry sheet. In addition, however, the actual effect of beating on wet web density is of great significance. Table I shows the density of an unbeaten and a beaten sulphite web over a range of solids contents in the wet web region.

Table I shows clearly that beating in this instance brings about a marked reduction in density in the wet web. Eventually at about 45% solids, the densities of the two webs are equal and with further drying, the density of the more highly beaten sheet becomes greater

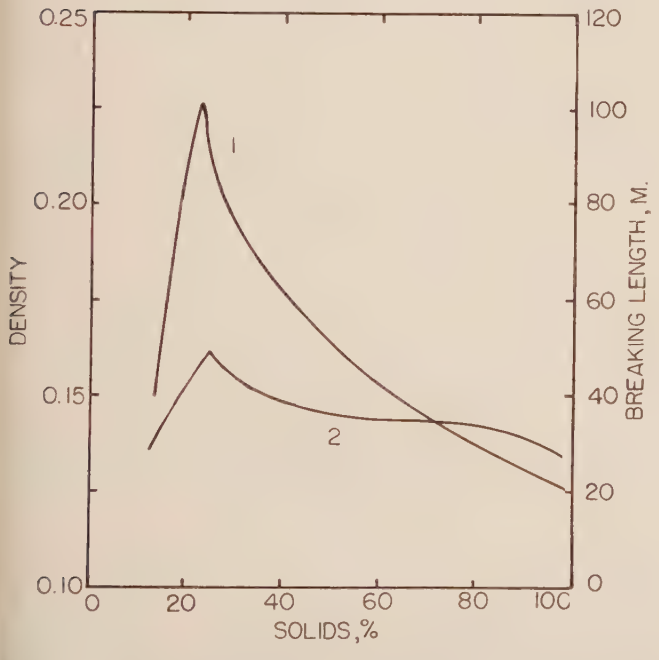

Fig. 3. Strength and density of glass fiber wet webs with increasing per cent solids; water removal by air drying

1—tensile strength, and 2—density.

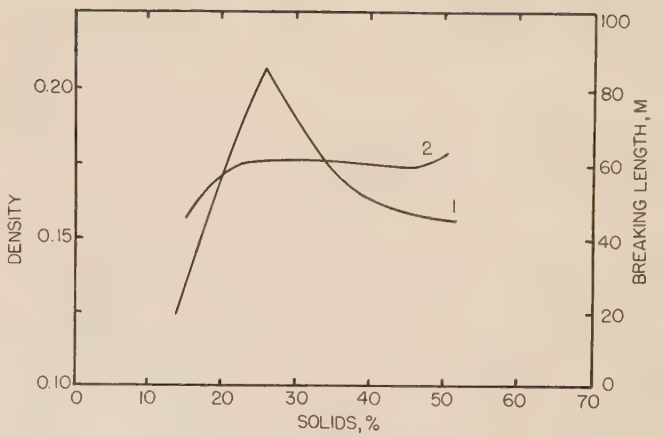

Fig. 4. Strength and density of glass fiber wet webs with increasing per cent solids; water removal by wet pressing

1—tensile strength, and 2—density.

than that of the lightly beaten sheet. Eventually on complete drying, beating brings about a markedly greater density. Despite the decreased density at low solids content, the wet web composed of beaten fibers develops a much higher strength. It is considered that this may be due to the earlier onset of inter-fiber bonding as a result of the enhanced degree of swelling of the fiber and its greater plasticity.

Table I. Effect of Beating on Density of Air Drying Sulphite Webs

Solids, %	*Density*	
	Beaten 10 min.	*Beaten 60 min.*
15	0.163	0.118
17.5	0.172	0.132
20.0	0.195	0.146
22.5	0.211	0.165
25	0.216	0.174
30	0.219	0.193
35	0.223	0.208
40	0.226	0.222
45	0.230	0.232
50	0.233	0.242

Figure 5 shows the effect of beating on the course of the strength development curve with increasing water removal by air drying. Curves 1, 2, 3, 4, and 5 represent data for sulphite pulp webs beaten for 0, 10, 20, 40, and 60 min., respectively. The freenesses in the same order were 684, 586, 387, 98, and 23, all expressed as C.S.F., milliliters. It is noted with progressive beating that the strength is markedly increased for the same solids content, and that the discontinuity at 20 to 25% solids is gradually reduced until it virtually disappears with 40 min. beating. It is considered that the explanation for this progressive change is similar to that given above for wet pressing. The disappearance of the inflections is interpreted as a smooth merging of the maximum in surface tension and a relatively high degree of early inter-fiber bonding.

Figures 6 and 7 show the effect of beating on density. Figure 6 represents the relationship of strength and density to per cent solids for an unbeaten spruce sulphite pulp web on air drying. The inflection point appears with both strength and density at 20 to 25% solids. Figure 7 represents similar data for a highly beaten spruce sulphite web, also with air drying. A

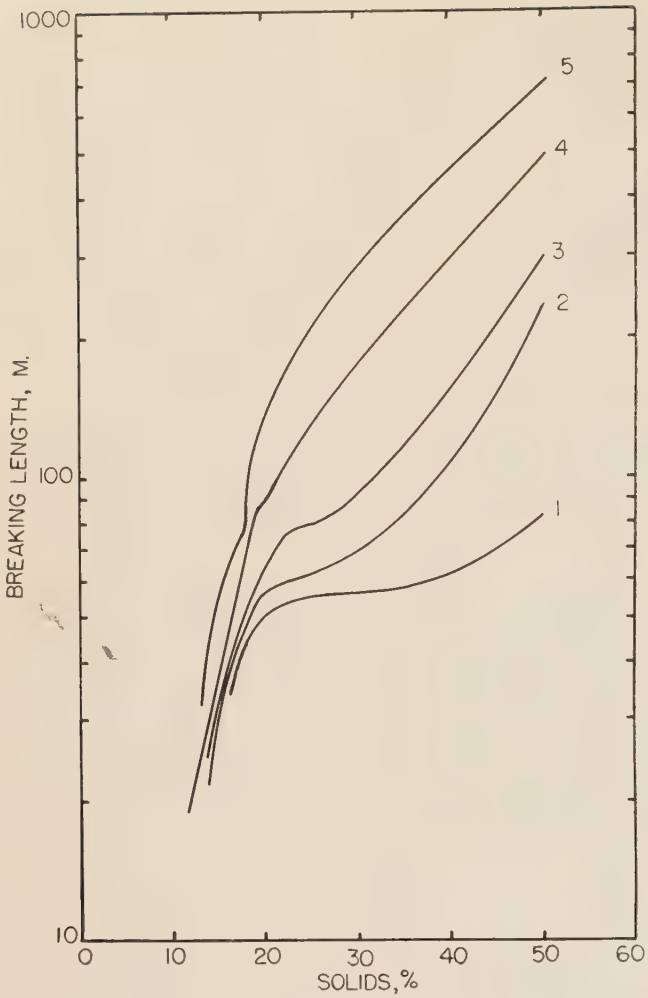

Fig. 5. Effect of beating on the strength development curve of spruce sulphite wet webs with increasing per cent solids; water removal by air drying

Beating times in minutes: 1—0, 2—10, 3—20, 4—40, and 5—60.

striking difference is noted in these relationships. Beating has brought about a smooth continuous development of both strength and density, with no appreciable discontinuity. This virtual absence of a discontinuity in density increase would appear to confirm the hypothesis of an earlier development of inter-fiber bonding in conjunction with enhanced and extended surface tension effects.

Air-Water Interface Considerations

As water removal from the wet web progresses, a stage must be reached where air enters the web. The percentage of air in the wet web by volume will be termed hereinafter the per cent voids. This per cent voids is simply calculated by the following formula:

$$\text{Per cent voids} = \frac{V_T - (V_F + V_W)}{V_T} \times 100$$

where V_T, V_F, V_W are the volumes of the wet web, the dry fibers, and the water contained, respectively. V_V is determined directly from the area of the wet web and its caliper. The latter was accurately measured by a magnetic caliper gage previously described (*4*), and a graphical method of attaining this measurement under zero load was used (*2*). V_F was obtained from pycnometric measurement of the density of the fibers used and their weight. V_W was calculated from the water content of the web.

It is apparent that the per cent voids must be related to the surface energy in the web and therefore, as shown above, to the strength development. Prior to the advent of an appreciable per cent voids, it would appear that the strength of the web must reside essentially in the mechanical entanglement and consequent frictional resistance among the fibers. As the per cent voids increases, the accompanying increase in air-water interface with consequent increase in surface energy results in greatly increased strength as shown above. The degree of dryness at which the per cent voids becomes appreciable is somewhat dependent on the caliper of the web as made on the sheet mold. Approximate data, however, are as follows. With unbeaten spruce sulphite, voids are appreciable at about 12% solids, and with highly beaten sulphite, voids appear at

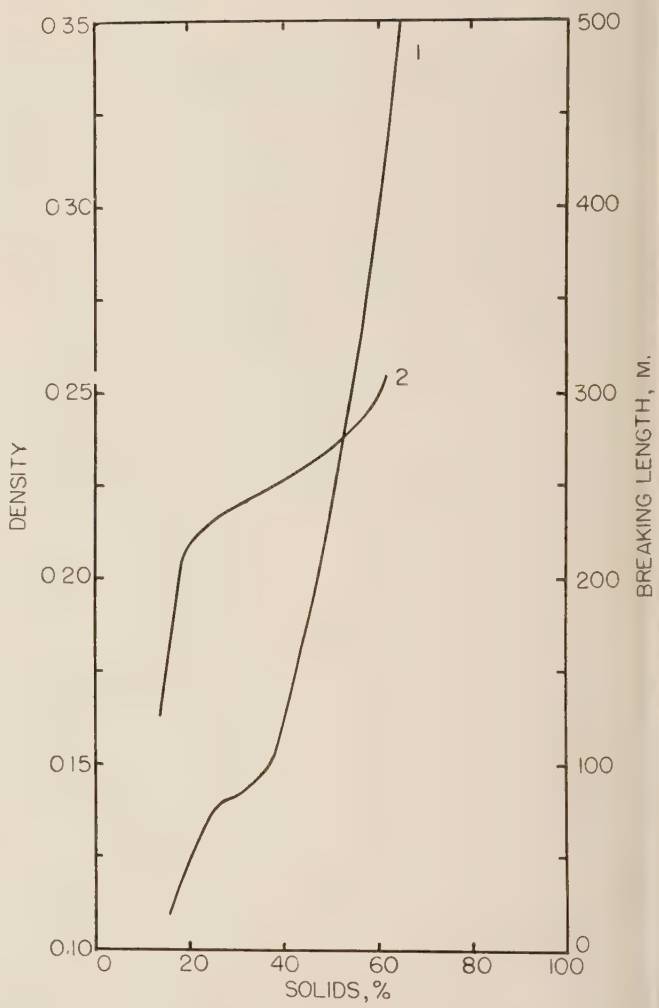

Fig. 6. Strength and density of lightly beaten spruce sulphite wet webs with incresing per cent solids; water removal by air drying

1—tensile strength, and 2—density.

about 10% solids. With spruce groundwood also, voids are appreciable at 10% solids. Even at solids contents, however well below the level calculated for the introduction of voids, it is clearly noticeable that the surfaces of such webs are not mirror surfaces which would represent the minimum of air-water interface.

It is apparent therefore that these web surfaces at much lower solids contents are rough to a degree entailing an appreciable air-water interface among the surface fibers. This exerts an appreciable strengthening force in addition to the above-mentioned frictional resistance among the fibers, and increases continuously with increasing solids content.

In view of the importance of surface tension as the major mechanism underlying strength development up to about 20 to 25% solids, it is of interest to note calculated relationships among strength, density, per cent solids, and per cent voids.

Figure 8 shows such relationships for spruce groundwood where water removal was effected by air drying (curves 1, 2, and 3), and by wet pressing (curves 4, 5, and 6). With air drying, it is noted that S-shaped curves are obtained for the relationships between per cent voids and strength, density, or solids. With

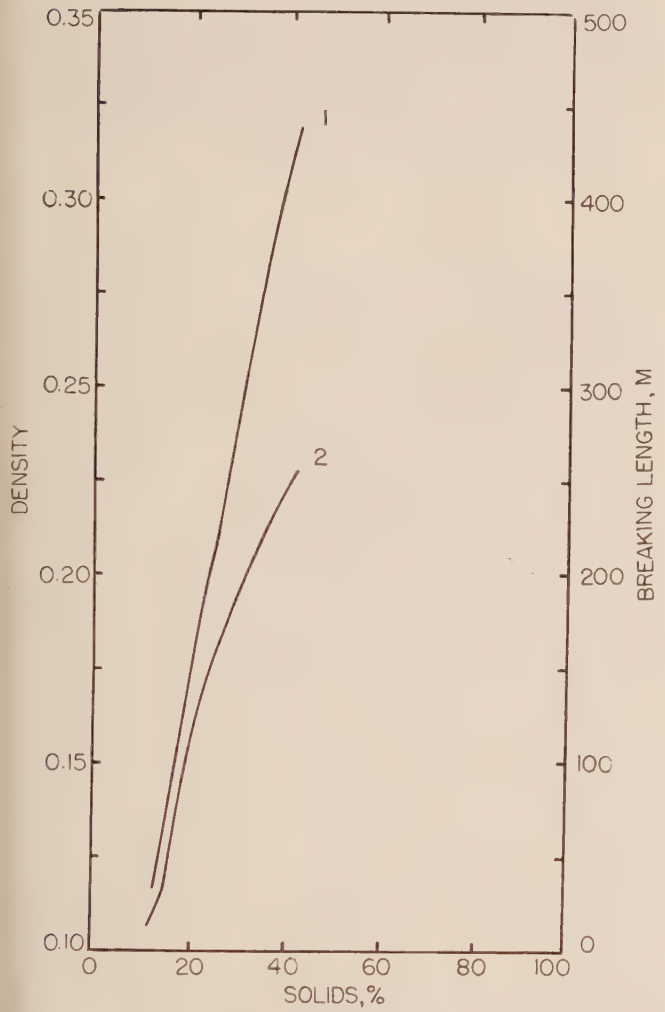

Fig. 7. Strength and density of heavily beaten spruce sulphite wet webs with increasing per cent solids; water removal by air drying

1—tensile strength, and 2—density.

water removal by wet pressing on the other hand, these relationships are essentially linear in the wet web region. It is conceivable that wet pressing might be carried out in such a manner that the volume of the web always equals the sum of the volumes of the fibers and the water remaining in the web. Actual measurements show, however, that voids are introduced at about the same per cent solids as in the air-drying sheets. With wet pressing, the voids increase linearly with water removal or per cent solids. Since the extent of air-water interface depends on the per cent voids and governs the strength in the wet web region,

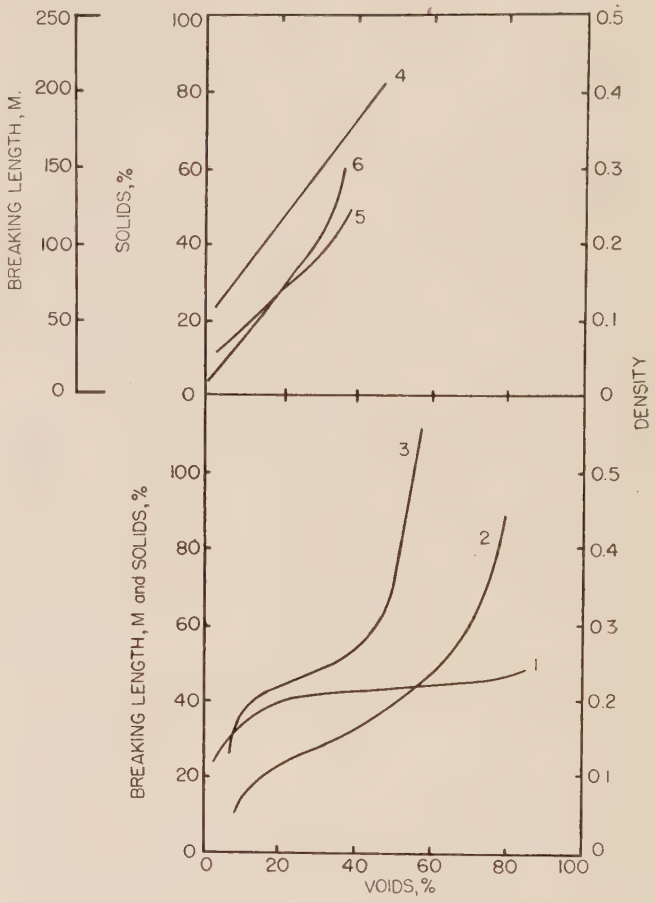

Fig. 8. Relationships of tensile strength, density, and per cent solids to per cent voids in spruce groundwood wet webs

Lower graphs—water removal by air drying. Upper graphs—water removal by wet pressing. 1 and 4—density; 2 and 5% solids; 3 and 6—tensile strength.

it would be expected that the strength would also increase linearly with the per cent voids. The density of the web is a function of the total volume of the fibers, water, and air, the weight being constant. Since the volume of the fibers is a constant, and the volume of the water varies inversely with the volume of the air (voids), the density must also vary linearly with the per cent voids. The linearity of these relationships holds for the wet web region prior to the predominance of bonding, i.e., where surface tension is the governing factor.

In the case of the air-drying web however, Fig. 8, curves 1, 2, and 3, the voids develop as a complex function of the per cent solids, as shown in curve 2. It would therefore be expected that the strength and density would also bear similar relationships to per cent voids. Curves 1, 2, and 3 of Fig. 8 are closely related to the strength-solids curve shown in Fig. 1 for the same groundwood, denoting two essentially successive mechanisms in the development of these properties.

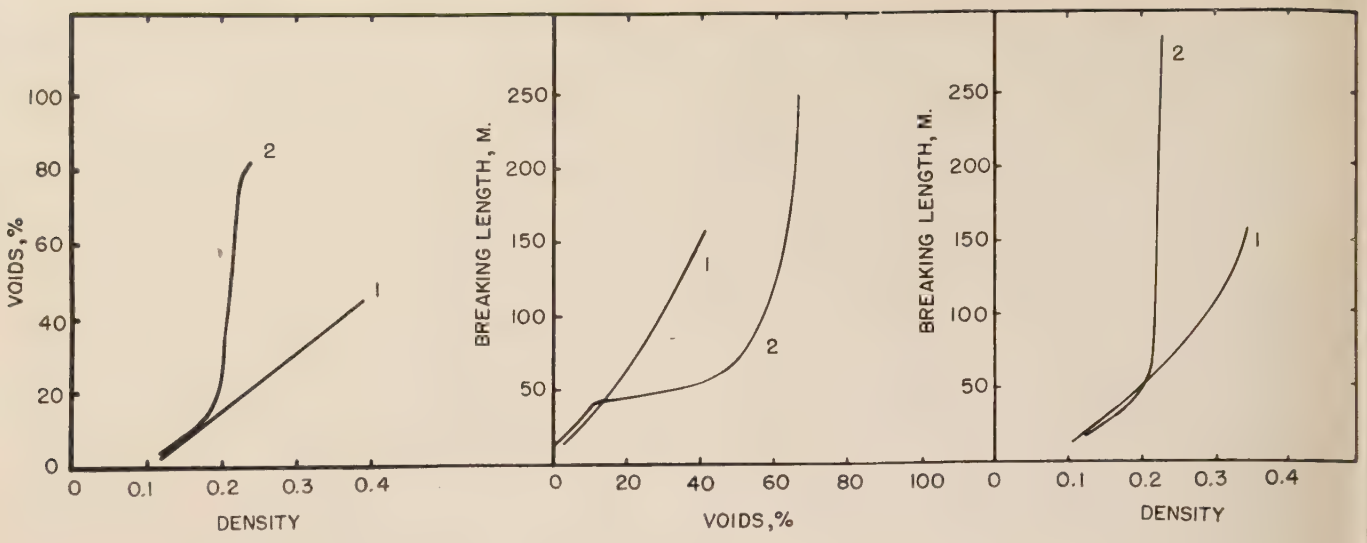

Fig. 9. Relationships among tensile strength, density, and per cent voids in spruce groundwood wet webs
1—water removal by wet pressing. 2—water removal by air drying.

Figure 9 shows another graphical representation of the same relationships among voids, density, and strength for airdrying and wet-pressed spruce groundwood. Curves 1 in each of the three graphs of Fig. 9 show the relationships for wet pressing, and curves 2 in each of the graphs show those for air-drying webs. It is noted in the left-hand graph of Fig. 9 that with air drying, the density parallels the per cent voids until the inflection region denoting maximum surface tension forces is reached, following which the per cent voids increases extremely sharply with little change in density. With wet pressing on the other hand, the per cent voids shows a linear increase with density. The middle graph of Fig. 9 shows relationships between strength and per cent voids, again noting the discontinuity with maximum surface tension forces in air-drying webs and an absence of this discontinuity with wet pressing. The right-hand graph of Fig. 9 shows a similar difference for strength-density relationships between air-drying and wet-pressed webs.

Figure 10 shows similar relationships for heavily beaten and lightly beaten spruce sulphite webs, using air drying in both cases. The effect of beating appears to be similar to that of wet pressing.

RHEOLOGY OF WET WEBS

A considerable amount of investigation has been devoted to studies of the rheology of paper in the dry state, principally by Steenberg, Andersson, Ivarsson, Nissan, Rance, Mason, and others, and the work has been well reviewed by Rance (*5*). These studies have made a valuable contribution to the understanding of the structure and physical properties of paper as well as to the improved manufacture of papers for specific end uses. Studies in the rheology of wet webs were undertaken by the present authors with the purpose of extending our knowledge of the structure and properties of wet webs and of studying the progressive changes in the properties of these webs during processing through to the dry state. It is emphasized that the work reported here is of an exploratory nature and that a very promising field of investigation has been initiated

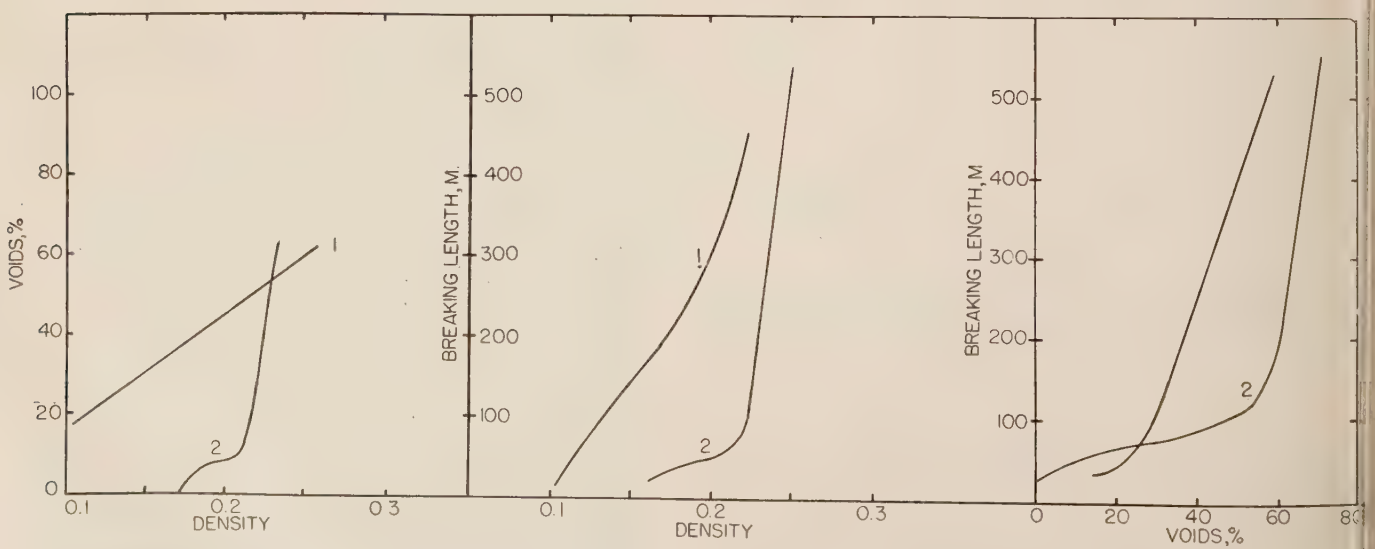

Fig. 10. Relationships among tensile strength, density and per cent voids in spruce sulphite wet webs
1—heavily beaten pulp; water removal by air drying. 2—lightly beaten pulp; water removal by air drying.

which will require a great deal of further detailed examination.

Instruments and Procedure

The construction and mode of operation of the wet web load-elongation measuring instrument has been

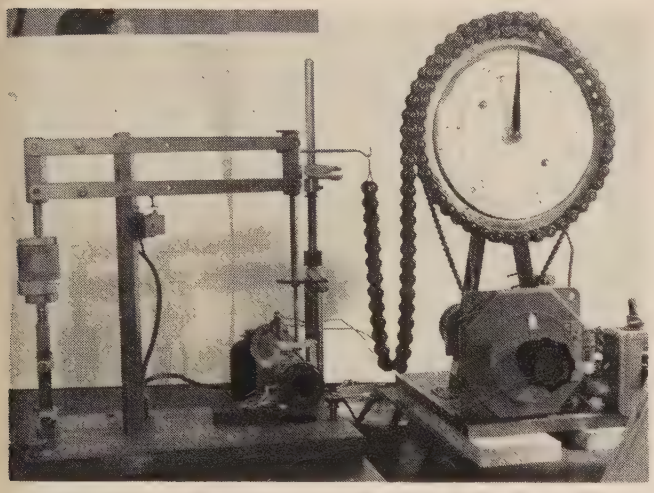

Fig. 11. Photograph of stress-strain apparatus for intermediate range of loading

previously described in detail (*1*). This instrument owing to sensitivity was limited in scope to measurements on pulp webs, the solids contents of which were less than 50%. In some of the studies reported below, it was necessary to go beyond this load level.

A second instrument was therefore constructed, more rugged in design, using chain loading and a parallelogram of 1/4 by 1/2-in. brass bars to transmit this load to an ordinary screw clamp. A ratio of 2 to 1 was established by placing the fulcrum two thirds of the way along the bars. With this unit, it was possible to load 1/2-in. test strips to a maximum of 7 lb. Screw clamps were found adequate for these stronger sheets. The elongation of the strips was measured by translating the motion of the arms through a diaphragm to the amount of light falling on a barrier-layer photocell. The output of this cell was fed into the X-axis of the recorder. The rotation of the drum holding the chain operated a potentiometer which in turn controlled the motion of the recorder along the Y-axis. Both of these motions could therefore be magnified electronically so that unit motions along either axis could be made equal to unit load and elongation. The responses of both the X and Y motions were linear with respect to load and elongation. The balance was sensitive to 20 grams when a load of 3200 grams was applied (0.6% load) and the elongation device was sensitive to 0.001 in. or 0.05% elongation. While the load at rupture of dry webs of sulphite could not be attained on this instrument, it was possible to load such strips up to 75% of their rupture load, the latter having been measured on a regular tensile tester. Figure 11 shows a photograph of the instrument described above.

There was thus available for these studies two stress-strain instruments covering a wide range of loading. Constant rate of loading was maintained on each instrument.

The wet web strips for this work were prepared according to the procedure previously described (*1*). Sixteen 1/2-in. strips or eight 1-in. strips were thus obtained and dried to the desired extent on a rotary turntable under an infrared lamp held 24 in. from the surface of the strips. It was found that this rotation of the strips produced more uniform drying, particularly with respect to the ends of the strips which had previously shown some tendency to overdry. At intervals, the turntable was stopped and the drying lamp turned off. The strips were covered with polyethylene film and one strip was removed and tested to rupture, recording the load and elongation on the X-Y recorder. A second strip was removed from under the protective film and loaded to 75% of the rupture load of the first strip. It was then deloaded to zero and reloaded to the same load level. This was repeated to the required number of cycles. In other studies cycling was carried out to other percentages of rupture load and to increasing levels of rupture load on the same strip, and then the loading was continued to rupture.

During these cycles, the web was covered with a light film of polyethylene which did not adhere to the wet web strip. The test strips were placed in a weighing

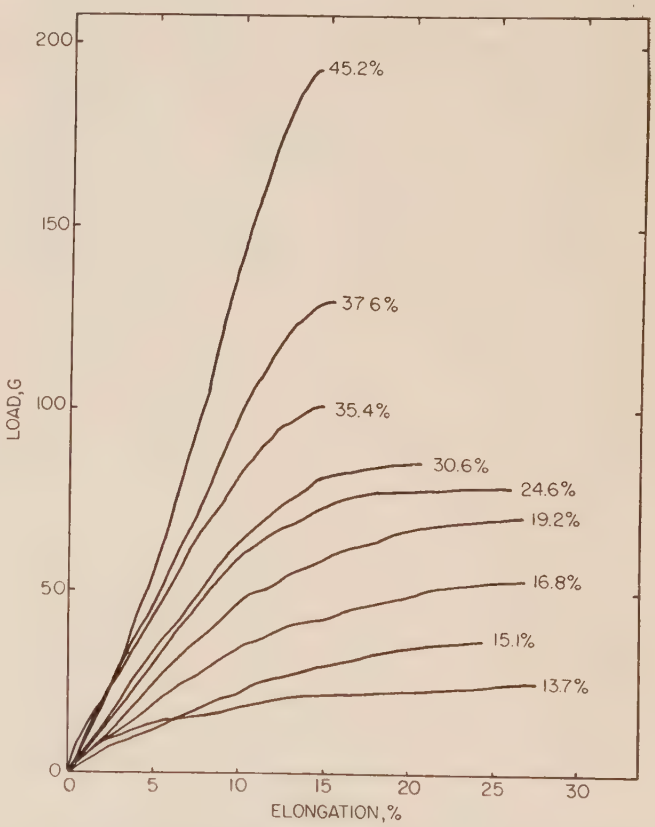

Fig. 12. Load-elongation relationships for spruce sulphite wet webs over a range of solids contents; autographically recorded

bottle immediately after rupture or prefailure testing and the moisture content determined. With these precautions, the moisture loss over three cycles of the strongest webs was only 1%. Weaker webs in the low solids region were cycled more rapidly and the loss was reduced proportionately.

Since the X-Y recorder was adjusted to even units for grams load and for per cent elongation, the areas under the load-elongation curves could be measured directly with a planimeter and converted to dyne centimeters. In the cycling of wet webs, it was of course impossible to delay successive cycles because of the changing moisture content with time. Thus the relaxation of strains, readily measurable in dry paper held under a fixed load, could not be investigated in these wet webs without undue experimental difficulties. Apart from time-dependent studies, all of the rheological properties commonly measured on dry webs could be determined on the wet webs down to 8 to 10% solids content with the instruments and procedures described above.

Load Elongation to Failure

General Relationships. Studies were made of the load-elongation curves on stressing webs of different solids content to failure. Figure 12 shows a typical group of curves for sulphite (C.S.F., 586 ml.) autographically recorded. The solids content ranges from 13.7 to 45.2%. It will be noted that the yield point occurs very close to the beginning of loading. It can be demonstrated by deloading that no appreciable portion of this curve shows purely elastic recovery. It should, however, be emphasized that the elongation obtainable prior to failure with wet webs is very much greater than that for dry paper and the scale of these curves is correspondingly greatly enlarged. An elastic or spring section, if actually present, corresponding to that commonly recognized for dry paper, would constitute only an extremely short section at the beginning of each curve. Actually in some among the very large number of load-elongation curves obtained, a distinct yield point appeared at about 0.3 to 0.5% elongation

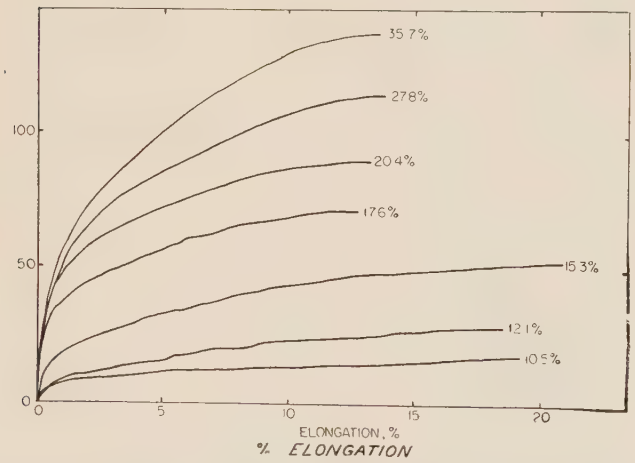

Fig. 13. Load-elongation relationships for spruce groundwood wet webs over a range of solids contents; autographically recorded

at very low load. This elongation for the yield point happens to correspond well with that noted by others for dry paper.

Figure 13 shows a group of load-elongation curves for spruce groundwood (C.S.F. 205 ml.) with solids content ranging from 10.5 to 35.7%. In general the form of the curves is not dissimilar to that for the sulphites. The elongation is considerably less with groundwood.

Figure 14 shows load-elongation curves for webs consisting of glass fibers of 2.5 mu diameter, having a solids content range from 16 to 99%. The curves for the webs with solids content from 18 to 24% show a

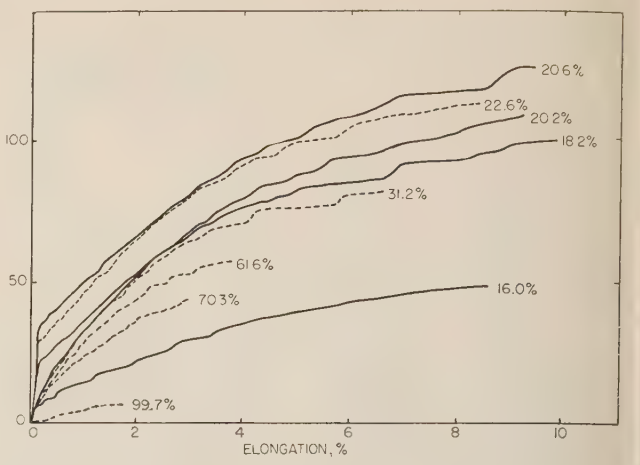

Fig. 14. Load-elongation relationships for glass fiber webs (2.5 mu diam.) over a range of solids contents; autographically recorded

marked steep rise in load with virtually no elongation, followed by a yield. This is not shown for webs having solids content of 16% or over 25%. It is further noted that smooth curves are not obtained with glass fiber webs and this was found to hold true throughout the course of this work. Actually, a stepwise development of the curve is obtained with glass webs, and this will be discussed in detail in a later section.

Figure 15 shows the general reproducibility of these autographic rheological measurements. Curves 1, 2, and 3 represent results for webs from the same pulp in repeated measurements at the same solids content. Curves 4 and 5 show results for glass webs of the same composition and the same solids content.

Strength. The strength at failure of wet webs over a wide range of solids content has been amply dealt with above.

Elongation. The per cent elongation at failure is much greater in wet webs than in the well-known data for dry paper. The elongation appears to follow the same development as breaking length with respect to per cent solids, involving an inflection point at about 20 to 25% solids. This relationship is not as clear with elongation in view of the higher coefficient of deviation involved.

Figure 16 shows the elongation of glass fiber webs consisting of fibers of different diameters and lengths. In all cases, there is a pronounced maximum in elongation at about 20% solids corresponding to the strength maximum. Curves 1 and 2 show that the elongation is less with greater diameter of fibers in the web, and curves 3 and 4 show that a lower elongation is produced with shorter fibers in such webs.

Changes in cross section on loading of dry webs to failure are well known (*6*), and dimensional changes in wet webs are also obtained. No attempt has been made, however, to recalculate strength or elongation in terms of unit cross section. It is interesting to note

that elongation increases with basis weight, the relationship being somewhat complex.

Work Capacity. Work capacity is defined for our purpose as the amount of work done on the web in loading the web to arrive at a definite elongation. It is determined by measuring the area under the load-

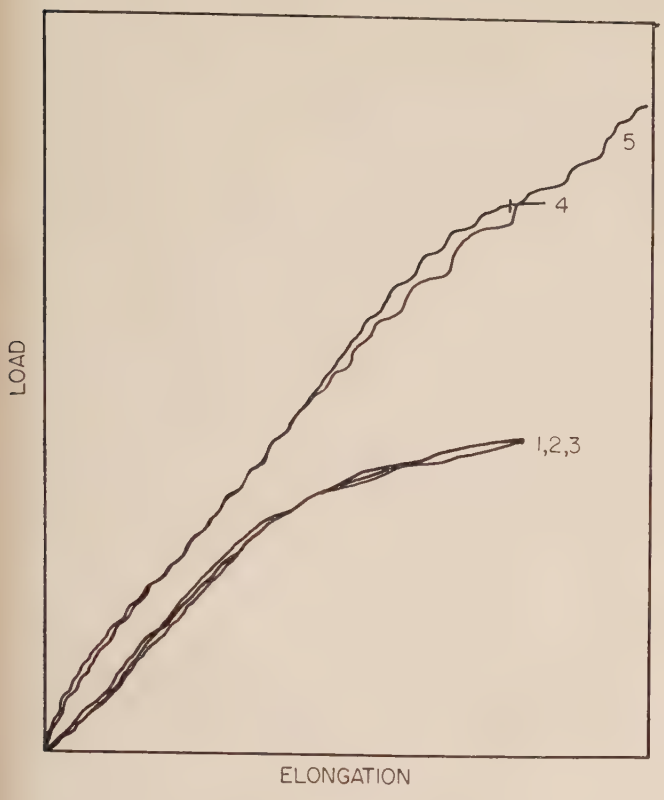

Fig. 15. Reproducibility of autographically recorded load-elongation relationships

Curves 1, 2, 3—pulp webs. Curves 4, 5—glass fiber webs. Each group has the same solids content.

elongation curve by means of a planimeter and the integrated product of load and elongation is expressed in dyne centimeters. Work capacity would appear to be a particularly important property of a web from the standpoint of specific requirements in the end uses of paper. In the case of wet webs, it may have particular significance with reference to the operation of the wet end of the paper machine.

Figure 17 shows work capacity for sulphite, groundwood, and glass fiber webs over a range of solids content. The left hand graphs are for sulphite (curve 1) and groundwood (curve 2). It is noted that a pronounced peak is obtained at 20 to 25% solids, i.e., the same region previously shown to be of outstanding importance in various properties of wet webs. The initial rise in work capacity is to be expected since both strength and elongation increase up to the inflection region. The subsequent decrease in work capacity would appear to be related to the decline in the first mechanism responsible for strength development, viz., surface tension forces. The second increase after the depression beginning at about 35% solids corresponds to the strong increase in the second mechanism underlying strength development, viz., inter-fiber bonding. This emphasizes the hypothesis previously advanced of two successive mechanisms in strength development in the wet web. Eventually the work capacity increases some tenfold at complete dryness.

The right-hand graph of Fig. 17 shows similar relationships for webs consisting of glass fibers of 0.75 mu diameter. A very pronounced maximum in work capacity is shown at about 20% solids, with a sharp decline to a negligible value at intermediate dryness. Similar maxima in work capacity were found for glass fiber webs of other diameters at about the same solids, the value of the maximum decreasing with increasing fiber diameter.

Structural Changes on Loading. In the course of this investigation, it was noted that smooth load-elongation curves were obtained with pulp webs, whereas apparently rough or irregular curves were consistently

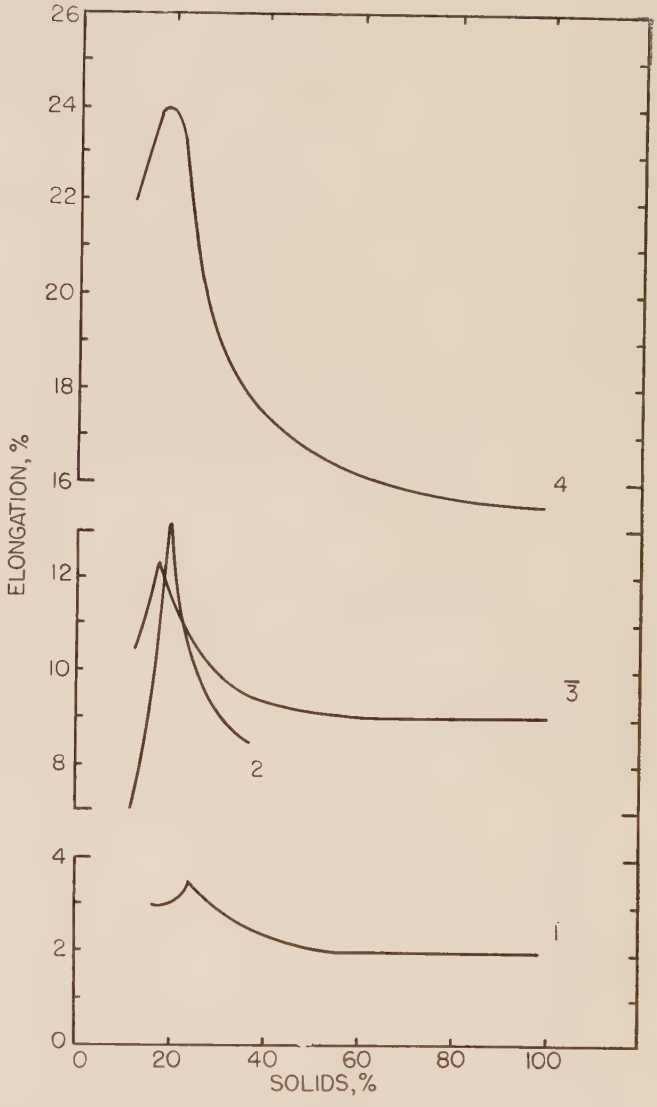

Fig. 16. Elongation of glass fiber webs over a range of solids contents

1—fiber diam. 3.8 mu, C.S.F. 511 ml. 2—fiber diam. 0.75 mu, C.F.S. 186 ml. 3—fiber diam. 0.25 mu, C.S.F. 35 ml. 4—fiber diam. 0.25 mu, C.S.F. 74 ml.

obtained with glass fiber webs, as shown in Figs. 12 and 14, respectively. In earlier work dealing with the effect of surface tension reduction on strength development, a very unusual load-elongation curve was obtained with glass fiber webs. All of these load-elongation curves were autographically recorded.

Figure 18 shows typical load-elongation curves for glass fiber webs (2.5 mu diameter) having the same per cent solids. Curve 1 represents the data for a web with no reduction in surface tension, and curve 2 shows the results for a web where the surface tension had been reduced to 33 dynes by the addition of an anionic surfactant. It is noted that this curve proceeds in definite stepwise fashion, the steps becoming larger with increasing loading. Many other autographic curves of similar webs have been obtained where the steps also consist of almost completely horizontal and vertical lines. The vertical components must represent structures having almost infinite friction, i.e., such structures must be considered as solids. The horizontal components represent structures having virtually zero friction, i.e., such structures must be considered as liquids. It is apparent that changes in structure of the wet web occur during increase in loading and elongation. The solid structure withstands a definite load with no elongation, and then yields to form a system which flows very readily with negligible added load. At the point of yield, an audible sound is heard of the same pitch and quality as that heard when a dry glass fiber web is held near the ear and flexed. Following this flow, a point is reached at which a new relatively solid structure is formed, and this cycle is repeated. It is altogether likely that both the fiber components and the aqueous medium are involved in this change of structure, i.e., successive redistributions of the water with consequent changes in surface energy are involved as well as the frictional resistance to slippage of the fibers. It has been noted, for example, that the steps in such load-elongation curves without reduction in surface tension are most marked where the surface tension forces and strength are at a maximum. Surface tension contributes strongly to resistance to flow and the liquid medium can redistribute itself during elongation.

It is noted that curve 1 of Fig. 18 also shows steps of small magnitude. Some minor indications of this stepwise development in load-elongation curves for pulp webs have also been observed, but the possibility remains that these supposed steps are within the limits of experimental error. It is apparent that such stepwise development should be more marked with webs consisting of fibers having a high modulus than with webs composed of relatively flexible fibers. It was noted, for example, that glass webs having fiber diameter of 0.25 mu showed steps of smaller magnitude than glass webs composed of fibers of 2.5 mu diameter. It may be logical to surmise on the basis of this work that the load-elongation curve for pulp webs is composed of a series of steps of very small magnitude which are difficult to detect. It would appear that the virtually vertical initial rise shown in Fig. 14 for webs in the region of 18 to 24% solids may represent an initial structure similar to the relatively solid structures described above as components of the steps.

In connection with the above, a simple experiment was carried out in the stress-strain instrument. A glass microscope slide was attached to each of the two heads of the instrument so that they overlapped in the test zone. A drop of water was applied between the plates. On application of load, no separation of the heads took place until a certain load was reached when the plates separated completely with virtually no

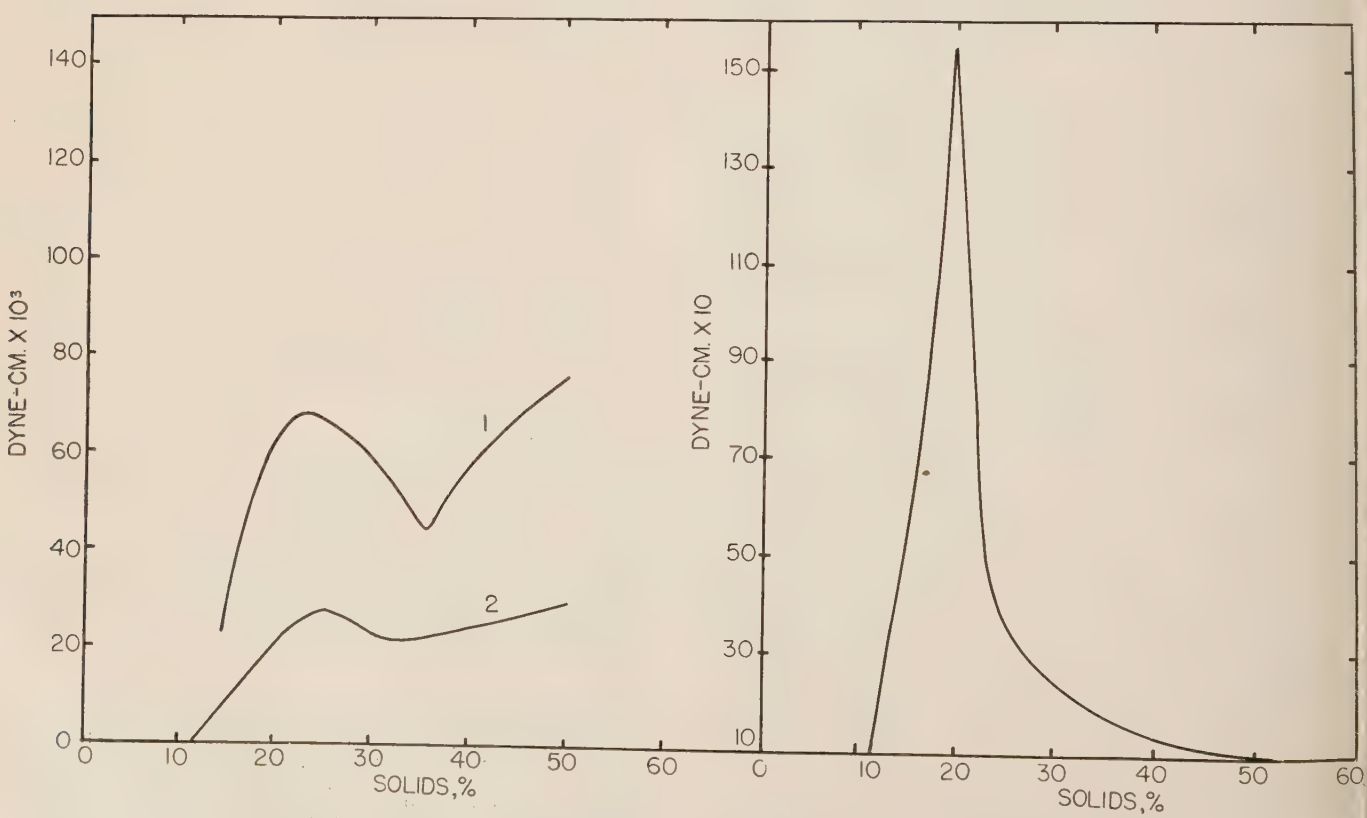

Fig. 17. Work capacity of pulp and glass fiber wet webs over a range of solids contents

Left-hand graph 1—spruce sulphite; 2—spruce groundwood. Right-hand graph—glass fiber webs, 0.75 mu diam.

increase in load. Repeated loadings with no further application of water resulted in the same sudden separation at successively greater loads until a stage was reached where the plates separated readily at a loading greatly below that of the initial cycle, presumably

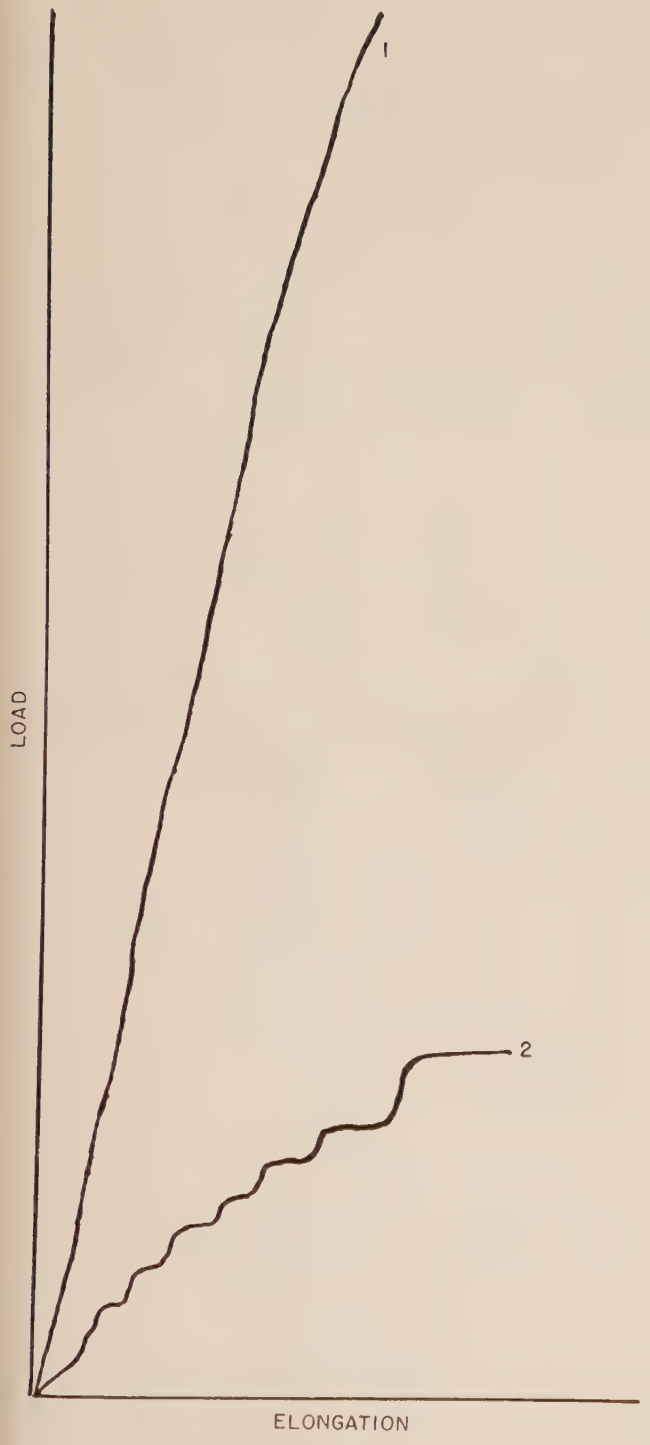

Fig. 18. Load-elongation relationship for glass fiber webs, 2.5 mu diam.; autographically recorded

1—surface tension, 72 dynes. 2—surface tension, 33 dynes.

owing to the breakdown of the water film. The load-elongation curves thus obtained are interpreted as simulating one step in the stepwise development for the glass-fiber web discussed above.

Rate of Loading. With dry paper webs, it is well known that the load required for failure is time dependent (*7*). This property is difficult of measurement in wet webs in view of moisture changes with time, but a limited number of determinations were made over short time intervals during which moisture losses would not be excessive for such data.

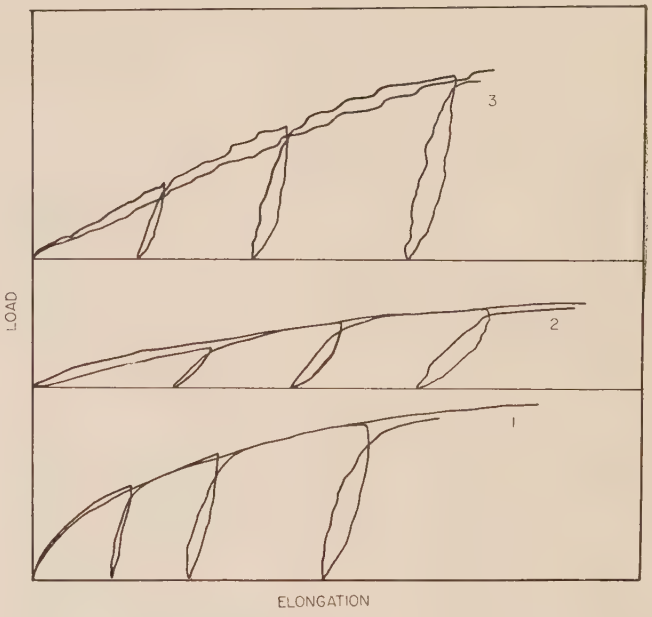

Fig. 19. Load-elongation relationships with and without recycling for wet webs showing memory effect, permanent set, and creep recovery; autographically recorded

1—spruce groundwood. 2—spruce sulphite. 3—glass fiber.

It was found that the load required to produce failure decreased with increasing time of application of loads less than those required to break the web in minimum loading time. Within the limited time intervals possible for these experiments, e.g., up to 300 sec., it appeared that the decrease in load required to produce failure was essentially linear with the time of load application. Wet webs thus show a similar behavior to dry webs in this respect.

Recycling

In the manufacture of paper, the wet web can undergo repeated stresses and relaxations from the couch to the driers and it was considered of interest to study the behavior of wet webs with recycling at various solids contents.

Figure 19 shows both continuous load-elongation curves to failure and loading and deloading cycles on the same webs at increasing fractions of their failure load, for groundwood (curve 1), sulphite (curve 2), and glass fiber (curve 3) webs. It will be noted that these curves show the same rheological properties as those for dry webs, including permanent set, recoverable creep, and memory effect. With groundwood and sulphite the coincidence of the continuous and recycled curves is excellent. In the case of the glass fiber webs the agreement is not as good as a result of the more rapid changes in load for a given moisture change. As previously noted, small changes in moisture content during these determinations are difficult to avoid experimentally. The solid contents for these three

representative curves were 16, 13, and 11.5% for the groundwood, sulphite, and glass, respectively. This conformity to the general form of recycled load-elongation curves for dry paper webs was observed down to the lowest per cent solids measurable on the wet web stress-strain apparatus.

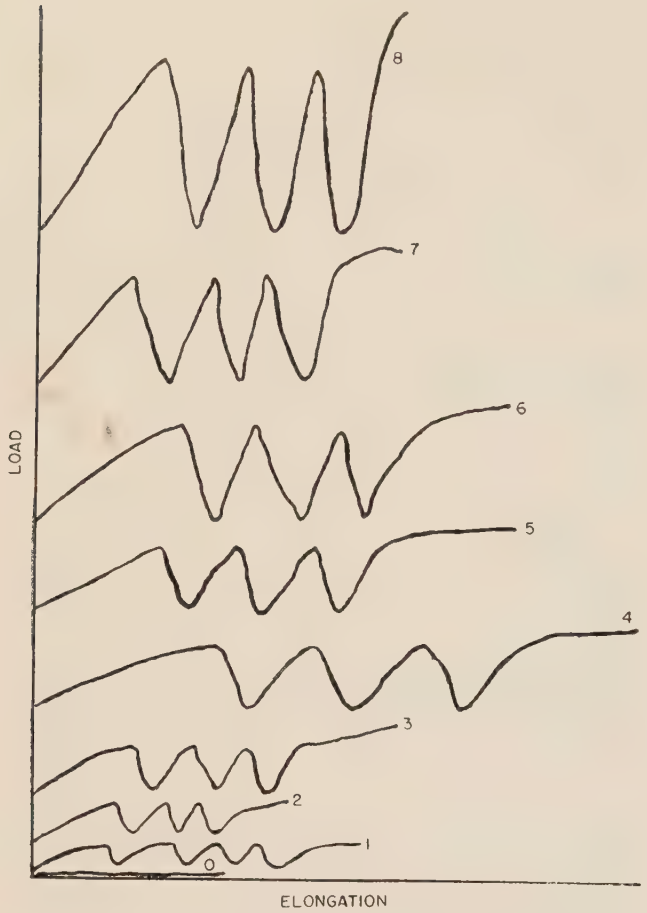

Fig. 20. Load-elongation diagrams for spruce sulphite wet webs over a range of solids contents

0—7.7%, 1—11.4%, 2—13.0%, 3—15.8%, 4—17.2%, 5—18.3%, 6—20.8%, 7—27.3%, 8—37.7%.

Figures 20, 21, and 22 show the changes in rheological properties of sulphite, groundwood, and glass webs, respectively, cycled three times at 75% of their respective failure loads. For each of the sulphite, groundwood, and glass webs, the data are represented over a range of solids contents from 8 to 35%. The deloading portions of the cycles are plotted as their mirror images for ease of representation. Solids higher than 35% could not be measured in view of the limitations of the instrument available at that time. The loading and deloading rates were adjusted to be the same in all cases. The total time required to complete the cycling on the strongest webs was less than 60 sec. On the basis of other data obtained, this represents a maximum loss of 1% moisture during the determinations.

The gradual change in slope of the initial load elongation is noted with increasing solids, as would be expected in view of the higher modulus with increasing dryness. The elongations with the sulphite and groundwood webs reach a maximum in the region of solids content associated with the inflections in the curves of strength development discussed earlier.

It is interesting to note that recycling has no effect on the load required for ultimate failure. This was found to hold true for all pulp and glass fiber wet webs.

Permanent Set and Recoverable Creep

It is noted from Figs. 20, 21, and 22 that the wet webs show clearly the phenomena of permanent set and recoverable creep, well known for dry paper webs. From the data obtained by recycling the wet webs three times to 65 to 88% of their failure loads over a

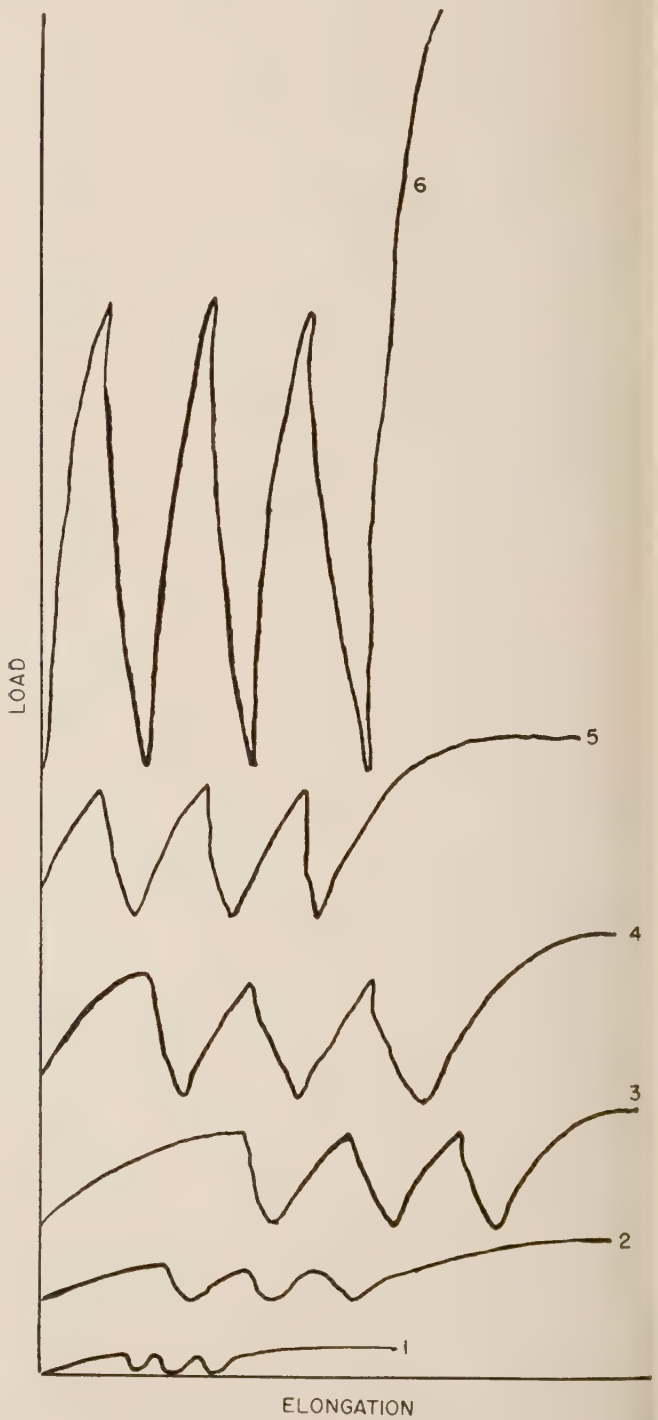

Fig. 21. Load-elongation diagrams for spruce groundwood wet webs over a range of solids contents

1—13.7%, 2—16.7%, 3—25.1%, 4—48.1%, 5—52.3%, 6—75.0%.

range of solids contents, the effects of the recycling on the magnitude of the permanent set was calculated.

Figure 23 shows the permanent set of groundwood and glass fiber webs for the whole range of solids contents after the first, second, and third cycles, denoted in each case by curves 1, 2, and 3, respectively. The left-hand group of Fig. 23 for groundwood shows sharp maxima in all cases at about 25% solids, i.e., the region of the inflection point of strength development. The three curves are parallel, the permanent set increasing with succeeding cycles. The right-hand group of Fig. 23 for glass fiber webs shows an exponential decrease of permanent set with increase in dryness. Here also the three curves are parallel with a slight increase in permanent set in successive cycles.

Data similar to those for groundwood were obtained with sulphite webs.

From the same recycling data, recoverable creep or reversible deformation was calculated for glass fiber, sulphite, and groundwood webs over the same solids range. The data are represented in Fig. 24, recoverable creep after each cycle being expressed as a fraction of the elongation of that cycle. This ratio represents the elasticity of the wet web. Again the results are expressed in curves 1, 2, and 3 after the first, second, and third cycles, respectively. The left-hand group represent data for sulphite, the middle group for groundwood, and the right-hand group for glass fiber webs.

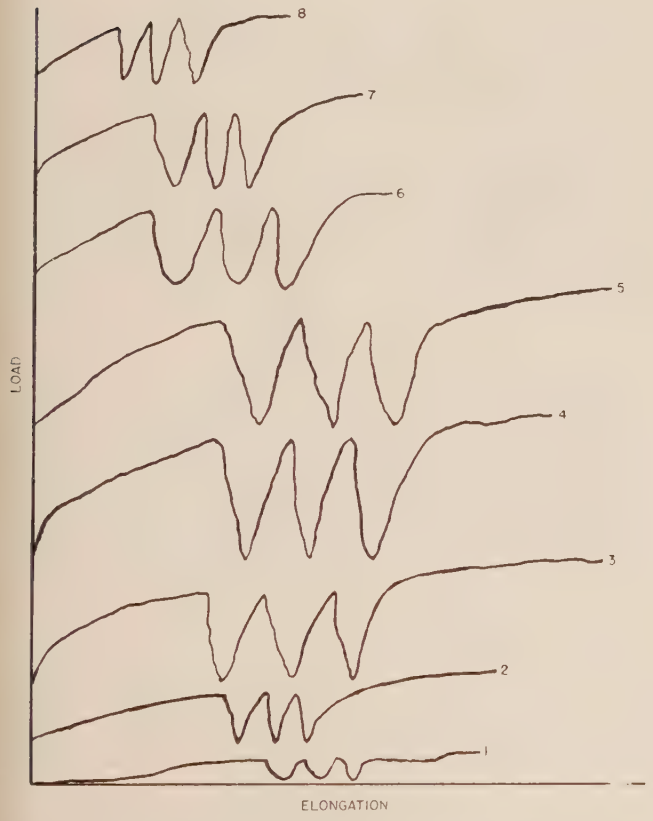

Fig. 22. Load-elongation diagrams for glass fiber wet webs over a range of solids contents

1—15.7%, 2—16.2%, 3—18.5%, 4—21.1%, 5—26.6%, 6—32.0%, 7—39.9%, 8—61.1%.

A maximum is noted for the glass fiber webs at about 40% solids, and this appears to bear no relation to the strength maximum shown earlier for glass fiber webs. The recoverable creep ratio increases with succeeding cycles.

An inflection is obtained in all cases with sulphite and groundwood webs at about 20% solids, again pointing to a relation with the inflection region in the strength development curve.

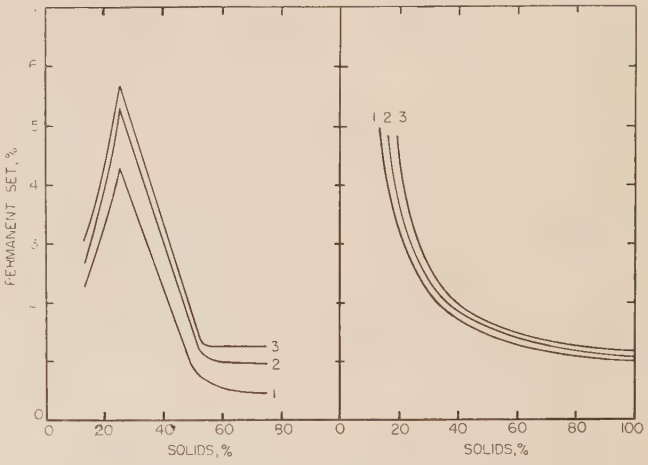

Fig. 23. Permanent set of groundwood and glass fiber wet webs over a range of solids contents. 1, 2, and 3 after first, second, and third cycles, respectively

Left-hand graphs—groundwood. Right-hand graphs—glass fiber 2.5 mu diam.

Resilience

Resilience is defined for the present purpose as the ratio of the area under the deloading curve to the area under the preceding loading curve. This ratio represents the fraction of the work previously put into the web which is immediately recovered.

Figure 25 shows the per cent resilience for glass fiber (left-hand group), sulphite (middle group), and groundwood webs (right-hand group) over a range of solids contents. It is noted that the resilience increases with increased drying in all cases. Similarly the resilience increases markedly with the second cycle and to a lesser extent with the third cycle.

Mechanical Conditioning

Mechanical conditioning in dry paper has been previously discussed (*8*). It was of considerable interest to determine the possibilities of mechanical conditioning in wet webs particularly at low solids. Referring to Figs. 20, 21, and 22, the amount of strain hardening or mechanical conditioning produced is very striking. Even with a solids content as low as 7.7%, which represents a wet web well back on the wire of a paper machine, the slope of the second loading curve is markedly steeper than that of the initial loading curve. This holds throughout for all of the webs over the whole range of solids contents measured. The slopes of the successive loading curves following the first are essentially the same. It is clearly shown therefore that a mechanical conditioning has been effected in the first cycle, following which the loading and deloading cycles produce virtually identical curves. The mechanical

Table II. Mechanical Conditioning—Work Hardening

Sulphite webs			Groundwood webs			Glass webs		
	Work capacity ratio			Work capacity ratio			Work capacity ratio	
Solids, %	2nd cycle/1st	3rd cycle/1st	Solids, %	2nd cycle/1st	3rd cycle/1st	Solids, %	2nd cycle/1st	3rd cycle/1st
11.4	69.8	55.8	12.8	65.3	86.9	13.7	16.5	10.4
14.9	68.4	32.1	13.7	46.9	47.3	16.2	15.0	8.7
17.2	38.9	33.5	15.7	35.7	71.4	18.5	23.6	24.7
17.7	41.3	38.5	16.7	41.0	36.1	20.5	25.4	17.6
22.1	39.6	28.4	21.0	31.5	44.5	21.1	22.7	23.2
42.1	47.7	42.2	25.1	37.6	25.6	23.2	24.6	20.5
53.4	49.4	43.0	48.1	55.9	48.9	26.6	21.1	17.0
			52.3	62.4	54.4	32.0	24.3	17.2
			75.0	67.9	57.3	34.3	29.5	27.5
						39.9	21.1	22.4
						61.1	23.0	18.4

conditioning in the case of glass webs is particularly great, the magnitude being much larger than that for sulphite and groundwood.

The ratio of the areas under the loading curves of the second and third cycles to those of the first cycle are given in Table II.

It is noted that the degree of work hardening shows a maximum with sulphite and groundwood webs in the region of the inflection point of their strength development curves with increasing solids. A smaller ratio in the second and third columns of Table II for each of the webs represents a greater degree of work hardening. The glass webs (2.5 mu diameter fibers) show an initial rise followed by a relatively constant ratio. Glass webs consisting of finer diameter fibers showed a maximum at about 18 to 20% solids, and a greater degree of work hardening than the pulps or the coarser glass webs. The third cycle showed somewhat greater work hardening than the second cycle in all cases.

Effect of Stressing Wet Webs on Dry Web Properties

Some preliminary experiments were carried out on the effect of preloading wet webs having solids contents from 15 to 40% on the strength and work capacity of the corresponding webs after complete drying. The wet webs were loaded to 0, 25, 50, and 75% of their respective loads at failure and then allowed to air dry freely. The dry webs were recycled three times at 50% of their failure load and then loaded to failure. For this series, the second test instrument of higher load capacity shown in Fig. 11 was used. In another series, webs with the same previous history were recycled at a fixed load well below the failure load, and then stressed to failure.

By prestressing the wet webs to increasing percentages of their loads, it might have been expected that the corresponding dry webs would be proportionately work-hardened. In the first series, however, it was found that the webs which had been prestressed to low percentages of their failure loads actually showed a reverse effect, i.e., an even greater capacity for dry work hardening, than that of the unstressed webs. It was not until the prestressing approached the failure loads, e.g., 75%, that the dry webs showed evidence of earlier work hardening.

In the series where the dry cycling was carried out at a fixed load, the effect of previous work hardening increased with the magnitude of the prestressing. A notable exception to this was found in those webs having a solids content in the region of the inflection in the strength development curve.

DISCUSSION

The dry paper web consists of fibers intimately intermeshed and bonded together at intervals. It has been amply shown that failure on stressing arises mainly from a slippage of the fibers over one another, rather than from failure of individual fibers. Inter-fiber bonding is therefore the most important strength mechanism, superimposed on resistance to failure re-

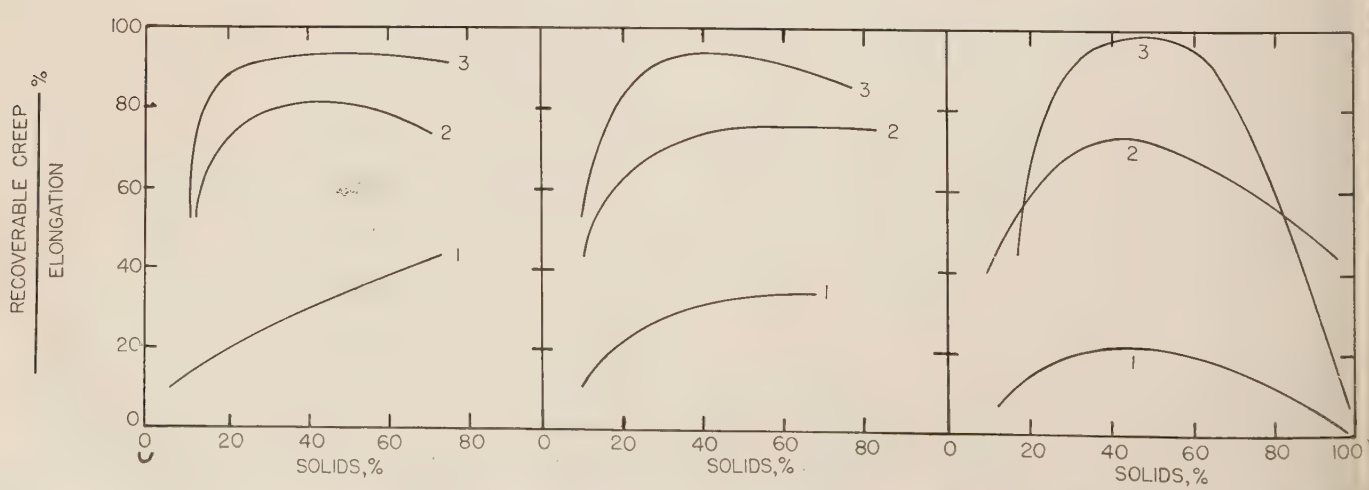

Fig. 24. Ratio of creep recovery to elongation for sulphite (left-hand group), groundwood (middle group), and glass fiber webs (right-hand group) over a range of solids contents. 1, 2, and 3 after first, second, and third cycles, respectively

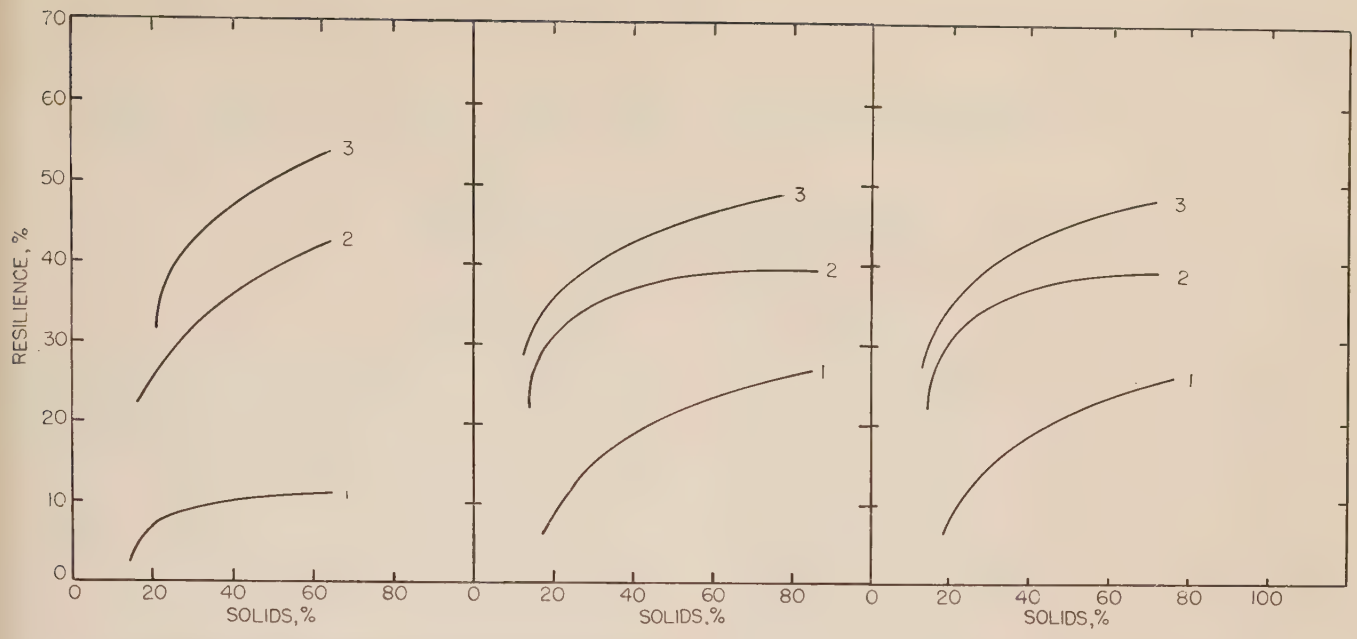

Fig. 25. Resilience of glass fiber (left-hand group), sulphite (middle group), and groundwood webs (right-hand group) over a range of solids contents. 1, 2, and 3 after first, second, and third cycles, respectively

sulting from mechanical entanglement, and consequent frictional resistance. On stressing, the web shows a progressive elongation. This deformation of the web probably results primarily from the straightening out of sections of the fibers between points of bonding, together with orientation in the direction of stress, and also possibly from a distortion of groups of fibers constituting a structural entity within the web. Eventually the limit of freedom of motion within the structure is reached and further elongation requires a breakdown of the inter-fiber linkages.

The behavior of dry paper webs on stressing and relaxation is intimately connected with the structure of the web as depicted above. The individual fibers themselves show both elasticity and plasticity on stressing in flexure and it would therefore be expected that the composite web would show much the same behavior. Purely elastic recovery from an elongating force would be obtained at best only up to a very small deformation. In view of the plasticity of the system, the web can recover only partially after deformation and a permanent set is obtained. The relative effects of elasticity and plasticity are time-dependent. With these dry paper webs, a memory effect is well known. Within the same limit of loading and deformation, the web can be stressed and relaxed repeatedly over essentially the same area without affecting the results on subsequent higher loadings.

It is of interest now to consider the structure of the wet web in relation to the properties discussed in this paper. The wet web consists of fibers arranged in a manner similar to that in the dry web, but with considerable differences in the medium, the distance between fibers, the degrees of plasticity and elasticity of the fibers, and the extent of attachment among them. Since a wide range of properties is covered in the wet web region, i.e., up to about 40% solids, it is necessary to speak of strength development rather than strength. Since inter-fiber bonding is very probably the primary basis for strength in the dry web, it is of particular interest to note the role played by this mechanism in wet webs. Considerable evidence has been adduced in these studies to show that inter-fiber bonding is not an important factor in the strength of very wet webs, i.e., below 20% solids. It has been shown however, that strength development does proceed markedly below this degree of dryness, and that the strength in this region is based on surface tension forces. Surface tension forces in turn are based on air-water interfaces and therefore the strength of the web at any point in this region must be closely related to the per cent voids present in the system.

Prior to the development of air-water interfaces (over and above the basic water-air envelope), it must be assumed that strength development is based entirely on mechanical entanglement and frictional resistance among the fibers in the water medium. This frictional resistance undoubtedly increases with dryness of the web and should be considered as superimposed on other mechanisms.

It is very likely that there is a close relationship between surface tension and inter-fiber bonding for the following reason. It has been clearly shown that surface tension forces bring about a higher density in the wet web and this increases with water removal. Thus a greater number of points of contact among fibers are established and inter-fiber bonding would be expected to increase.

The air included in the volume of the web must necessarily appear initially at inter-fiber spaces on the exposed faces of the web. With progressive drying and increase in void volume, the air replaces water at increasing depths in the web, with development of greater air-water interface. It would appear that thus groups of fibers are held together by water films through surface energy. The per cent voids may be considered therefore as the basic factor in the structure on which the strength and accompanying properties depend in the very wet webs. The surface tension forces thus produced are reflected in the progressive reduction in vol-

ume or increase in density of these very wet webs with water removal. It is interesting to note that the magnitude of this contraction and increase in density is much greater than the increase in density brought about by the whole range of subsequent inter-fiber bonding.

These two successive mechanisms underlying strength in the wet web region are not entirely separate. It has been noted that inter-fiber bonding is assisted materially by the increase in density during the predominance of surface tension forces. Similarly, although the latter reach a maximum at 20 to 25% solids and decline quite rapidly thereafter, a residuum remains in the subsequent predominantly inter-fiber bonding region. By means of wet pressing, both mechanisms are strengthened and a smooth merging and consequently a smooth curve of strength development is obtained without the discontinuity so marked for air-drying webs. Similarly, beating brings about an earlier development of inter-fiber bonding with consequent elimination of the inflection. In dry paper webs, beating is associated with greater density. In wet webs, however, beating actually brings about a marked decrease in density which is, however, associated with a higher wet web strength.

It might be well to avoid confusion between the application of surface energy in our concept developed in this work, and that involved in the classical theory of inter-fiber bonding advanced by Campbell many years ago (*9*). Surface energy at very low solids contents draws together groups of fibers through water envelopes, such groups being interconnected both through the position of the fibers and through the water films. It has been amply shown in this work that this mode of action of surface energy reaches a maximum at about 20 to 25% solids and then decreases rapidly. The action of surface energy at solids contents where the fibers themselves begin to shrink, i.e., above about 80% is, however, exerted at a localized portion of the surfaces of two adjacent fibers which undergo shrinkage in contact with each other. It is thus seen that these two applications of surface energy in strength development in the fibrous web are quite distinct in nature.

It is obvious that the term "inter-fiber bonding" in this paper is not used in the literal sense as applied to the last portion of the drying of the web. It is used rather in the sense of "inter-fiber adhesion," representing a degree of adhesion among fiber surfaces which are considered as an important contribution to the developing strength of the web. This concept of inter-fiber adhesion has been developed previously at some length by one of the authors (*3*).

The rheological properties of wet webs down to very low solids bear a remarkable similarity to those of the dry paper webs. It is interesting to relate these well-defined properties to the concept of the structure and underlying strength mechanisms for the wet webs discussed above.

The elongations obtained on stressing wet webs are very much greater than those for dry webs. It must be assumed that the elongation at failure in very wet webs, e.g., 10% solids, is necessarily of intermediate magnitude, i.e., about 11%, in view of the low level of strength development. In dry webs, the elongation at failure must be very low as a result of intensive inter-fiber bonding. At intermediate dryness, however, the elongations are strikingly high reaching values of 25% at failure. A maximum is shown at the per cent solids corresponding to the maximum in surface tension forces. Thus it would appear that the latter can allow a very high degree of deformation in fibrous webs as a result of the ability of the air-water interface to distort markedly and probably also to re-form after disruption. Such disruption of air-water interfaces and subsequent re-formation might occur repeatedly with deformation of the solids in the structure. This is strikingly shown in a pronounced stepwise course of the load-elongation curve for glass fiber webs. These steps were greatest in magnitude at a degree of dryness corresponding to the maximum in surface tension forces.

The work capacity also passes through a peak corresponding to the maximum in surface energy and then decreases prior to the large increases later obtained with marked inter-fiber bonding at greater dryness.

These wet webs show typical permanent set, recoverable creep, and resilience. The permanent set shows a very pronounced maximum at the same degree of dryness as the maximum in surface energy in these wet pulp webs. The ratios of permanent and recoverable creep to the elongation show an inflection in this region. The same holds for resilience.

Thus it appears that these properties increase with increasing surface energy reaching a maximum level within the experimental range with maximum in surface energy. On deformation, these wet webs show retractive forces. The latter must be surface tension forces below the inflection point. The air-water interfaces must be purely elastic in nature *per se*, but they are visualized as capable of re-forming after disruption and therefore the whole system is also plastic in nature in view of the ability to retain a deformation in the reformed structure. Thus the wet webs prior to the large predominance of inter-fiber bonding are considered to possess both elastic and plastic properties. The resultant effect is therefore similar to that of dry paper webs, but the basic mechanism is quite different. This resultant effect is then reflected in the various rheological properties observed and described earlier.

The concept of the structure of the wet web developed above combined with the previously commonly accepted structure in the dry web would appear to offer a generalized concept of the structure of the paper web during its manufacture. Further studies are planned in an elaboration of the work reported above.

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The Functions of the Felt in Water Removal on the Papermaking Machine

ALFRED H. NISSAN

This paper is limited to the discussion of factors involved in water removal only. The main features of fibers and yarns, and of spinning and weaving methods involved in felt manufacture and which have bearing on water removal are summarized. A discussion on suction press felts follows. The state of the paper web is shown to consist of a pattern of wet spots in a less wet matrix. It appears that the chief properties of the felt of significance to water removal are (1) a low modulus of compressibility; (2) a high absolute value and rate of recovery from compression, and (3) a high permeability to water. A test for felts is suggested based on these ideas. A theoretical basis is found for the practical observation that high temperatures should improve the rate of water removal on the press. Finally, in a discussion on why wool is used so extensively in wet felts and why the particular structure of woolen felts is adopted, it is shown that the molecular, subfibrillar and fibrillar characteristics of wool as well as those of the yarns, weave structure and finishing methods adopted, do in fact correspond closely to the theoretical requirements of an ideal wet felt. In the next major section drier felts on multicylinder driers are again discussed from the point of view of water removal. It is found that on fast machines the felt is used mostly as the means of applying pressure to the sheet. A brief discussion reveals a mechanism which should contribute to the speed of water removal on the first driers by liquid absorption of the water but which is apparently absent in high speed machines. It is then shown that certain puzzling features of previous work on slower machines can be explained on the basis of this mechanism. It is suggested that felts for the first few driers of high speed machines should be designed to take advantage of this mechanism and thus enhance the rate of water removal from the web in the first few driers. A brief discussion is made of the chief characteristics to be imparted to this type of felt.

Felts are used on the paper machine to do more than simply remove water from the web. In concentrating attention on this particular function, it is necessary to bear in mind that certain other factors, like the tendency of the felt to mark the delicate sheet of paper, the resistance of the felt to abrasion and to other forces which tend to shorten its useful life, its dimensional stability and similar properties will be considered by the papermaker as well as its ability to help in water removal. In this paper, however, only the factors which help or hinder water removal will be considered.

One other limitation has to be remembered. The paper will deal with fourdrinier-type machines running at medium and high speeds. The author's experience—mostly of newsprint—rather than the relative importance of the uses of the felt in different types of machines has determined this limitation.

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Before embarking on the main theme of the paper it may be useful to give a brief outline of the processes involved in felt manufacture and of their characteristics.

FELT MANUFACTURE AND CHARACTERISTICS

Fairly recently, Race (*1*), Collins (*2*), and Starkie (*3*) have discussed in some detail the manufacture and characteristics of felts used in papermaking. Here, only the high lights of the processes and properties involved will be picked out to indicate which factors should be considered in studying and using felts. Thus, the principal properties of the main fibers used in felts and only those items in the processes of direct significance to the user of the felt will be indicated.

Fibers

Wool is almost universally used for wet felts and cotton for drier felts. Variations, however, exist. Woolen felts are also used in the drier sections on fine papers. On the other hand, up to 25% nylon is sometimes added to the weft of woolen felts to increase the life of the felt where abrasion is severe. Experiments are being carried out with all nylon wet felts too. Asbestos fiber is used as facing for some drier felts which have to contact cylinder surfaces at high temperatures. Terylene is being experimented with, but no results are available as yet. Thus, at present, wool cotton, nylon, and asbestos are probably the chief fibers of interest to the papermaker. Table I gives the principal properties of these fibers. In Fig. 1 curves are presented to demonstrate the rheological properties of wool, nylon, and cotton when they are immersed in water as happens in wet felts. Each fiber was subjected to a cycle of straining followed by un-straining and finally re-straining to breaking point. Note the superlative strength of nylon and the remarkable elastic recovery of wool in water.

Before fibers can be used in papermaking felts, they have to be spun into yarns, then woven into cloth, and finished as felts.

Yarns

To produce yarns from fibers a number of operations are necessary. These vary according to the nature, length, diameter, and cleanliness of the original fiber as well as the final properties required from the yarn as a thread in weaving and from the felt as an ultimate material of industrial use. Generally speaking, the fibers undergo processes of cleaning and drying followed by a "carding" process in which the fibers are first laid down in a very thin uniform sheet, and then the sheet is either condensed into one cylindrical sliver or divided into a number of thinner cylinders. After several steps of blending and drawing, these are then spun into yarns

Table I. Principal Properties of Fibers Used in Felts

Properties	*Wool*	*Cotton*	*Nylon*	*Asbestos*
Rheological (only typical values are given as actual values depend on the specific source of the fiber and method of test; 100% variation can occur in some of the values given)	Breaking length in air (65% R.H.) and in water approximately 15 km.; elongation at break in air = 35% and in water at 65°F. = 50–55%; recovers incompletely in air, but completely in water from all extensions	Breaking length in air (65% R.H.) = 37 km.; in water = 41 km. approximately; elongation at break in air = 10% and in water = 12% with incomplete recovery except for small elongations in both air and water	Breaking length in air (65% R.H.) = 52 km.; in water = 45 km. approximately; elongation at break in air and water = 13–25% with 100% recovery from, say, 8% and 91% from 16% extension	Although asbestos possesses high tensile stress at break (up to 210,000 p.s.i. when dry compared with, say, 100,000 p.s.i. for nylon) extension at break is very small, consequently fiber is brittle
Water absorption	Adsorbs from 14 to 16% of its moisture-free weight from air at 65% R.H.; 33% of its moisture - free weight at 100% R.H.	Adsorbs about 8–9% of its moisture - free weight from air at 65% R.H.; 25% of its moisture - free weight at 100% R.H.	Adsorbs about 4% at 65% R.H. and about 6% at 95% R.H.	Fairly hygroscopic but no exact figures are available to the author
Chemical stability	Slowly discolors at temperatures above 220° F.; severe discoloration above 285°F.; acids weaken it but the effect is reversible and strength is regained on washing; concentrated solutions of weak acids cause swelling; alkalis destroy it, especially alkaline reducing agents	Slowly discolors at 285° C. and over; acids tender cotton and should be avoided; alkalis mercerize it at high concentrations but cotton withstands alkalis better than wool	Yellows slightly at 302° F.; melts at 482°F.; sensitive to concentrated mineral acids and to weak organic acids; inert to alkalis; very sensitive to bleaching materials	Very stable against heat; fairly inert to ordinary materials met on drying paper
Biological properties	Attacked by moths, but can be permanently proofed against them; under alkaline conditions liable to attack by slime unless chemically treated	Resistant to moths, but is liable to attack by mildew unless proofed against it	Inert; moths eat through it if trapped	Inert

by a process of "drafting"—i.e., reducing the diameter by stretching and allowing the fibers to slip—and then twisting. Sometimes they are first subjected to operations which align the fibers more or less parallel to each other before spinning. Where the yarn is produced without first aligning the fibers, the fibers stick out in all directions and a "fuzzy" yarn is produced—necessary, for instance, where a felt with a good raised nap is required. On the other hand, where the fibers are first aligned, a relatively smooth surface is the result—again necessary where the felt is to be smooth, e.g., the under side of a felt to be used on suction presses. Figure 2 shows the two different schemes. Not only the general systems—and there are many of these—are important, but even the type of spinning machine finally used to spin the yarn is believed by many to be of extreme importance. While many hold the view that yarns can be produced on a ring spinning frame as good as those spun on a mule, some manufacturers use only mule-spun yarn for the weft to provide the uniformly soft, cushioning cover for their felt faces, while others use the mule for both weft and warp with a claim to obtaining the most out of the fiber qualities.

Weaving

Weaving consists of interlacing weft and warp yarn at right angles to each other to produce the cloth. There is an infinity of possibilities for the manner in which the yarn can be interlaced. By choosing the warp and weft characteristics and their mode of interlacing, a corresponding number of variations in cloth characteristics can be attained. Only the barest outline of this topic can be given here.

The simplest mode of weaving is the "plain weave" illustrated in Fig. 3. Although this is a "simple" weave structure, by varying the yarn diameters and stiffness for weft and warp and altering the closeness of weave (number of threads per inch), a great number of different cloths can be produced using plain weave structure only. The main characteristic to be remembered in connection with the plain weave as far as felts are concerned, however, is that it probably gives the most open structure commensurate with a given weight and strength of cloth.

Sometimes it is necessary to provide the face of the felt with more of the weft yarn than of the stronger but harder warp. To do this, the weft is allowed to ride over more than one warp yarn (say two, three, or four) on the face side of the felt and to go under only one warp yarn on the under side (see Fig. 4). To strengthen a cloth further, a "compound cloth" can be woven by using more than one set of warp ends (or wefts) and weaving simultaneously two cloths which are automatically "stitched" on the loom by taking a warp (or weft) thread occasionally from one side and incorporating it in the other. Figure 5 illustrates a compound cloth. Such a design used in a wet felt is the "double plain" design whereby the open structure of the plain weave has been retained to give high permeability to water, together with a weft-face cover. Figure 6, taken from E. Race's paper (*1*) illustrates this structure. Figure 6(a) is a cross section through a straight warp and Fig. 6(b) a cross section through a straight weft and they show how the face is weft-covered and why the felt is called "double plain." Figure 7, taken from the same paper, illustrates a three-layer structure

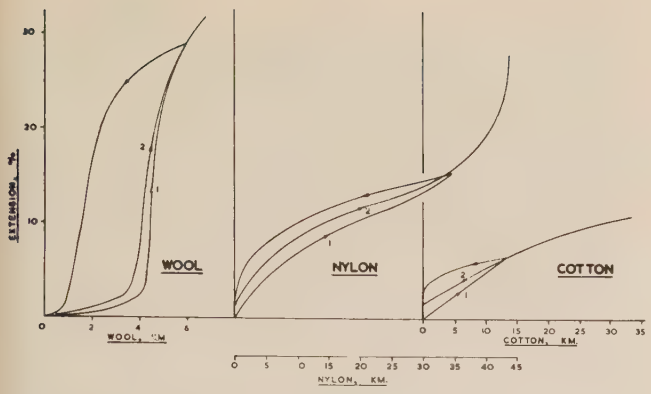

Fig. 1. Stress/strain curves for wool, nylon, and cotton obtained with the fibers immersed in water

Note: Wool rate of extension and retraction = 22% per min.; no rest after first cycle. Nylon rate of extension and retraction = 15%; no rest after first cycle. Cotton rate of extension and retraction = 100% per min.; 1 min. rest after first cycle.

cotton drier felt. More complex structures—up to eight layers—are used on some fine paper machines requiring extra soft bulky drier felts made of cotton.

Finishing Operations

Once again, the felt maker uses a very great variety of operations on the felt before he considers his felt as finished. Some of these operations completely alter the character of the loom-state felt. The most spectacular changes are wrought in woolen wet felts. After the usual cleaning operations, the felt is subjected to "milling"—a long series of alternating compression and relaxation in warm soapy water of controlled pH. The wool fibers migrate and become entangled, causing the felt to shrink, sometimes by as much as 50% on the loom-state width, producing a denser and more compact felt which is still resilient and compressible. Afterwards the fibers on the surface are "raised" on revolving cylinders carrying teazles or wires to produce a nap. Figure 8 illustrates the appearance of the cloth—woven specially in two colors to reveal the changes—before and after milling and raising. It will be observed that the yarn and weave structure are completely obscured after these operations by the milling shrinkage and by the nap raised on the felt. On the other hand, where a smooth surface is required, say, against a suction press cylinder, the surface fibers are sometimes singed. Wet and dry heat treatments as well as chemical treatments to increase the resistance of the felts to bacterial attack are selected and applied at this stage in accordance with requirements. Similarly, if seamed felts are required they are seamed endless in the finishing department.

This discussion on feltmaking has been restricted to those points which will be of some significance in the study of the functions of the felt in water removal. Consequently, no more than the bare outline of only some of the many processes involved has been presented. No comprehensive treatment is either possible or intended in such a short and selective outline.

THE FUNCTIONS OF THE WET FELTS IN PRESSES

It is essential, though not always possible, to distinguish between observation, interpretation, and speculation when the fundamentals of a process are under study. An attempt will be made here. Quite early, however, it will be clear that the three strands of observation, interpretation, and speculation on what takes place in the presses are intricately intertwined even in what appears at first to be a simple observation of the state of the paper web as it enters the nip. Afterwards, speculation on what goes on in the nip itself increases while observation assumes vanishing proportions. After the nip the amount of observed evidence increases again.

Figure 9 is a photograph of a newsprint paper web, taken by a high speed flash, when the sheet approached the couch and then left it on its way to the first press. The need for interpretation is obvious. The key to the interpretation lies in the black line to the right of the picture, which represents the effect of the water jet at the deckle of the machine. The line, which is continuous at first, breaks when it meets a horizontal line, indicated by the head of the arrow A. There is the appearance of a mark of lighter shade at the point of break. After the break a series of black dashes are interspersed by whitish marks until the line meets another horizontal one indicated by arrow C when it appears partly to re-form into a more continuous though attenuated line. This seems to show that when the line first hits a vacuum by coming over a hole it is sucked in. At C, it meets the sealing strip and partly re-forms. The significant point in this interpretation is the assumption that a lighter shade on the photograph implies less water in the sheet.

Accepting this interpretation, it appears then that at C a horizontal dark line shows a "water-jump" or wave tending to make the sheet more uniformly wet over the sealing strip. Afterwards, there are two regions, B in the side strip and D in the body of the sheet. At B (the strip which remains stuck to the wire before it falls off into the pit) impressions of white holes still persist. Where the sheet parts from the wire, as in D, there is a reversal—a pattern of dark spots appears, corresponding to the holes in the couch shell and indicating that where the sheet was opposite a hole it is actually wetter than when it was against a solid part.

If speculation is allowed here, the mechanism of this

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Fig. 2. Woolen (above) and worsted yarn (below)

pattern may be as follows. Since the pattern is quite sharp, there appears no evidence of lateral movement of water in the wire, and hence it probably has as much water—if not actually more—in its interstices over a solid part as over a hole. As the sheet separates off the wire, however, a suction is produced tending to suck back the water from the wire into the sheet. (This suction is aided by centrifugal forces, but it is sufficient by itself for the purpose even without centrifugal forces as will be seen in interpreting similar phenomena after the presses.) Where the wire interstices are backed by a solid, the water is partitioned between the paper and the wire. Where there is a hole, there is no hold for the water by which it can cling—apart from the surfaces of the wire strands—and consequently most of it is re-absorbed into the web. If this speculative interpretation is correct, certain deductions concerning the design of the couch shell hole geometry and the point of paper take-off intrude themselves on the mind; these are outside the scope of this paper, however.

Thus, to summarize, it may be concluded as mostly a matter of observation that the sheet approaches the press nip as a more or less regularly patterned sheet of wet spots in a less wet continuous network.

The next point of observation is that at the entry into the nip the sheet and felt are compressed and flooded with water. In the nip itself nothing more has been noted except that the felt is in a compressed condition. After the nip, the felt appears to recover its thickness and the sheet surface, as photographed, presents one of two appearances. If the press is solid then the sheet is of uniform white shade as shown in Fig. 10, taken both above and below the sheet. Thus, the spotted pattern is completely obliterated. If the sheet is passed over a suction press the sheet once again reveals a pattern of dark spots on a light continuous network. That this pattern is not an artifact due to lighting conditions is seen from Fig. 11 which shows the pattern of the sheet both as seen from above and below the sheet. Figure 11 was taken after the third press of a newsprint machine; similar photographs show no significant difference between the other suction presses.

Once again, it is necessary to interpret these ob-

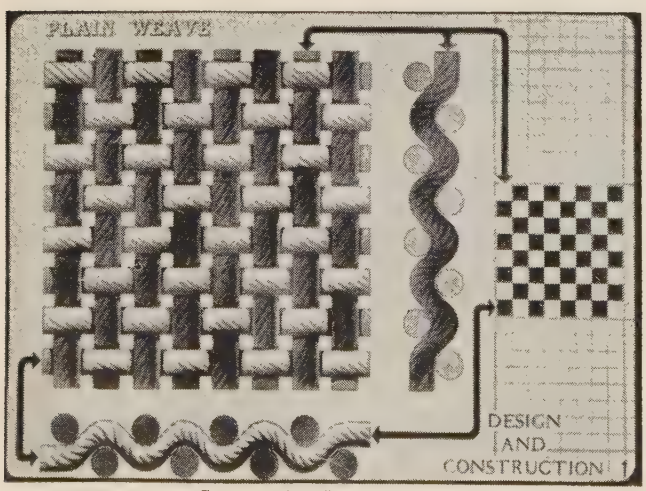

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Fig. 3. Plain weave design and construction

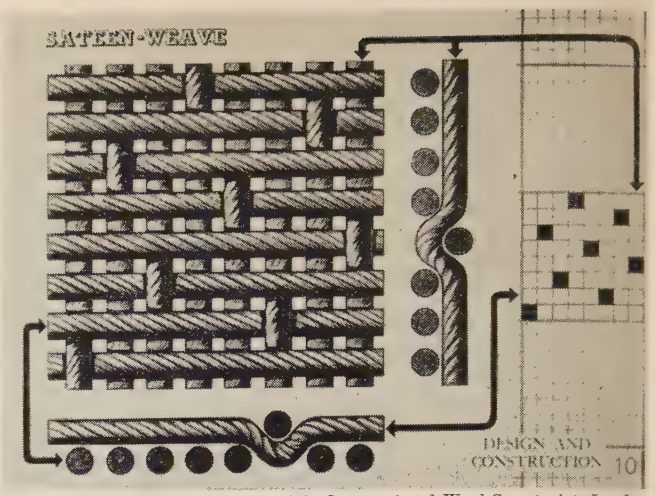

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Fig. 4. Sateen weave design and construction

servations with a judicious amount of speculation. It appears that at the entry into the nip the felt and paper are compressed and water is extruded. The water which is extruded is unlikely to have come from the web for Jahn and his colleagues (*4*) have shown that the paper web can retain surprisingly large quantities of water under very high pressures for a considerable period of time. It will be assumed that, in fact, the water comes mostly out of the felt, though some may come out of the paper. Thus, in the nip both paper and felt must be considered to be saturated with water. The effect of pressure at the nip is to compress the felt and (aided by the vacuum in suction presses) thus reduce the total quantity of water remaining in its interstices. As the sheet and felt leave the nip, both expand. The total quantity of water is then partitioned between web and felt. The forces responsible, according to this analysis, are therefore: (1) elastic forces in the felt tending to restore the original thickness of the felt and thus creating a vacuum to be filled either by water from the sheet or by air and (2) surface tension forces which will displace the air from the capillaries.

Thus, ultimately, a significant question can be asked and partly answered. What characteristics are necessary in a wet felt to assist water removal in the presses? (The question of other characteristics—e.g., supporting the web without marking—need not be considered here.) The answer is that the felt should have several properties:

1. To create a suction the felt must compress easily to a very small volume in the nip without the necessity of excessive pressures which may crush the sheet.

2. A felt which simply collapsed under pressure would not be of great value if it did not recover its original volume immediately after the release of compression. Delayed elasticity and recovery and other delights of rheological sophistication are of little significance. Immediate reduction of volume followed by immediate recovery—and both in large measures—are required.

3. These properties should be retained in the wet, slightly acid conditions of papermaking—i.e., the fibers should clean easily and not "make-up" too quickly.

4. On expansion the felt absorbs the water by capillary forces coming into play. Thus, where the felt is compressed against the hard solid portion of the shell, it absorbs more water than where there is a hole—hence the pattern after the press. It is useful to inquire further into the mechanism of flow under sur-

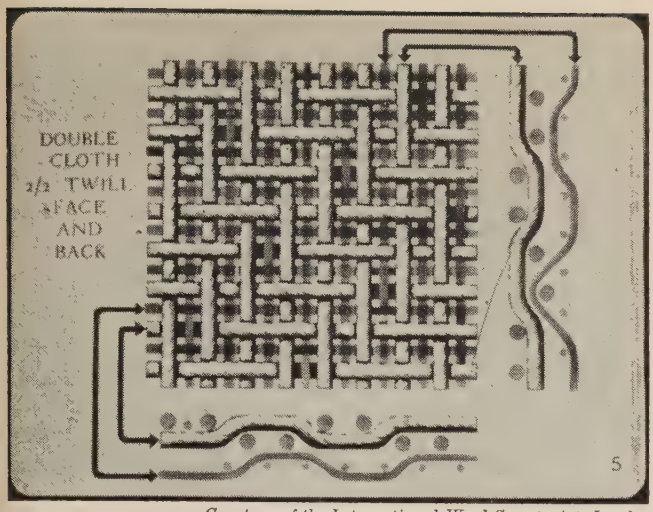

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Fig. 5. Double cloth, illustrating how two cloths are woven and "stitched" to give one compound cloth

face tension forces in order to see if other hidden factors can be revealed.

Palmer (*5*) worked out how liquids flow into porous materials like yarns when frictional resistance, gravity, and capillary forces are acting, and obtained equation (1) for the passage of liquid up a single capillary:

$$t = \frac{3\mu}{\rho g m^2 \sin\lambda}\left[\frac{\gamma\cos\theta}{\rho g m \sin\lambda} \times \log\left\{\frac{\gamma\cos\theta}{\gamma\cos\theta - \rho g m z \sin\lambda}\right\} - z\right] \quad (1)$$
$$= B\left[A\log\left(\frac{A}{A-z}\right) - z\right]$$

where

t = time for liquid to advance distance z into a capillary
μ = viscosity of liquid
ρ = density of liquid
g = a gravitational constant
m = hydraulic mean depth of capillary
λ = the angle of inclination of the capillary from the horizontal
γ = surface tension
θ = angle of contact

The acceleration of the liquid was considered negligible. All terms are in self-consistent units.

Other than θ, equation (1) has only one characteristic of the felt, m the hydraulic mean depth which affects the speed of advance of the liquids into the interstices. This parameter, m, can be derived according to equation (2) from the permeability of the material to water, measured in consistent absolute units, and has the dimension of length.

$$\text{Permeability} = \left[v \Big/ \left(\frac{\Delta P}{L}\right)\right] = \frac{m^2}{\mu k} \quad (2)$$

where

v = average velocity of flow
$\left(\frac{\Delta P}{L}\right)$ = pressure gradient in direction of flow
k = a dimensionless shape factor which is approximately constant

No "special" property is demanded by the fact that the driving force is due to capillarity. As the only other force is due to the differential pressure created by the vacuum produced on expansion of the felt after the nip, it is then apparent that the permeability of wet felts to water is the primary property involved in water removal.

Palmer was interested in the whole history of the movement of water in fiber matrices and developed his equations accordingly on a comprehensive basis in which he finally eliminated m from the equations. In wet felt operations the time of contact is a fraction of a second, compared with the several hundred minutes required for approaching "infinite time" in equilibrium experiments. Hence, it will probably be permissible to simplify Palmer's equation (1) for the strictly practical problem of wet pressing. Thus, for the short time involved in press operations z, the length traveled by the water is very small compared with A, the equilibrium height to which water could travel. Hence $\log [A/A - z]$ can be expanded and simplified, whence by ignoring powers of (z/A) higher than 2,

$$t = \frac{1}{2}\frac{Bz^2}{A}$$
$$= \frac{3}{2}\frac{\mu z^2}{m\gamma\cos\theta} \quad (3)$$

The volume of water in each capillary is equal to

$$V_i = z_i a_i = z_i m_i s_i = \pi z_i m_i d_i \quad (4)$$

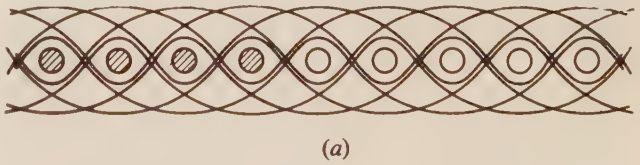
where

V_i = volume in the ith capillary
a_i = cross-sectional area of the ith capillary
$= m_i s_i$
s_i = the length of the air fiber perimeter of the ith capillary
$= \pi d_i$
d_i = diameter of the ith capillary, if it were circular

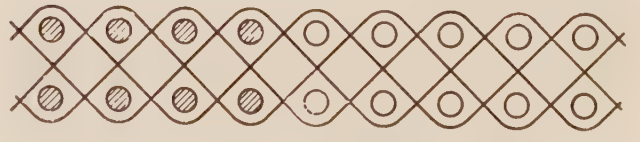
Thus, the total volume V advancing into the felt in a *short* time t is given by

$$V = \Sigma V_i = \Sigma\pi\left(\frac{2}{3}\frac{m_i\gamma\cos\theta t}{\mu}\right)^{1/2} m_i d_i$$
$$= (2.55)\cdot\left(\frac{\gamma\cos\theta}{\mu}\right)^{1/2}(t)^{1/2}\Sigma m_i^{3/2} d_i \quad (5)$$

This means that for a given (short) time of relaxation and contact, t, and for a given felt made of water wettable fibers (i.e., $\theta = 0$) designed with a given value for $[\Sigma m_i^{3/2} d_i]$, the total volume of water abstracted by the felt from the sheet is proportional to the square root of the ratio of surface tension γ to the viscosity μ of the water. This ratio increases with temperature and thus



(a)



(b)

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Fig. 6. "Double-plain" felt

(a) A cross section through a straight warp showing the weft faced nature of the felt due to the four-end irregular sateen weave structure. (b) A cross section through a straight weft, showing the so-called "double-plain" structure.

pressing at high temperatures helps water removal by the felt as can be seen from Table II. As often happens, the papermaker has been putting this observation into practice for a considerable time by keeping his stock warm and by sometimes putting heaters between his presses.

Table II

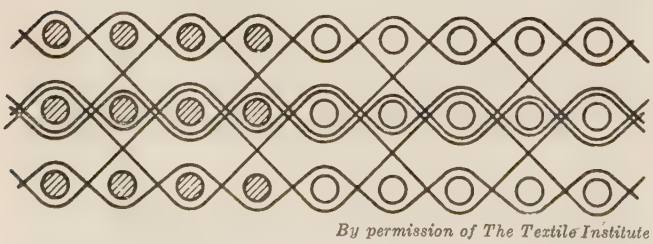
t°F.	$(\gamma/\mu)^{1/2}$
100	101
130	114
160	127
190	138
210	142

Reverting to felt characteristics, it appears from equation (5) that one of the chief requirements—insofar as water removal is concerned—is to keep $[\Sigma m_i^{3/2} d_i]$ [or $(\Sigma m_i^{5/2})$ since m_i is a linear function of d_i] a maximum. This, in turn, means that the interstices should have maximum dimensions compatible with other requirements—e.g., nonmarking of the sheet demanding a close surface structure.

Thus, the three requirements for the felt, in order to remove the maximum amount of water per pressing operation are (1) high compressibility or low modulus of compression, (2) high recovery at rapid rates or high values of resilience, and (3) high permeability to water. A felt which maintains these three qualities for the longest time under the working conditions of the paper machine will have fulfilled its requirements satisfactorily.

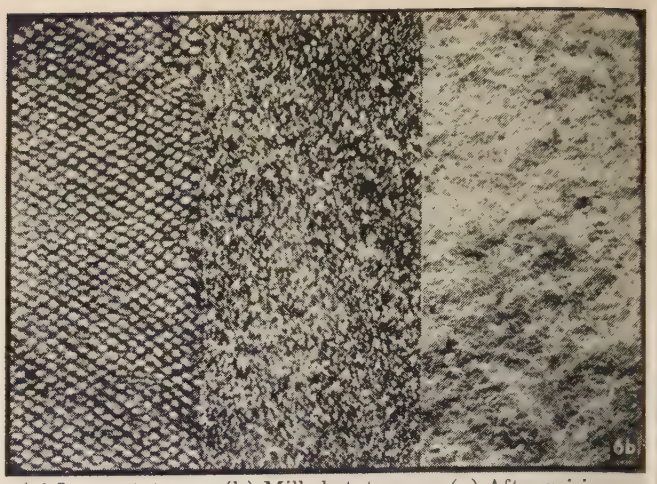
Permeability to water is a regular nondestructive test of felts. The analysis suggests that an informative test would be the measurement of the compressibility modulus and rates and extent of recovery at the beginning and end of a cycle of high speed compression under water at, say, pH 5. Half a million cycles at, say, 1200 cycles a min. would take 7 hr. and would represent a week of running time.

By choice of the fiber, its method of conversion into yarn, the weave structure, and the finishing operation, the feltmaker aims at fulfilling these requirements as well as the other mechanical and chemical demands made on the felt. This section may be closed by asking: how far do papermakers and felt manufacturers utilize specific properties of the felt on the paper machine to meet these requirements? For example, woolen felts are almost universally used for wet pressing —why wool? And, indeed, why felt? Would other fibers, would other constructions do just as well? Conversely, are there valuable properties specific to wool or to felt construction going to waste in that they are not being fully utilized? Furthermore, if wet felts are to be made of other fibers than wool, which properties should be retained, and if possible enhanced, and which eliminated?



By permission of The Textile Institute

Fig. 7. Three-layer drier felt of 5.5 to 6 oz. per sq. ft. for coarse and medium papers



(a) Loom state. (b) Milled state. (c) After raising.

Courtesy of the International Wool Secretariat, London

Fig. 8. Illustrating the change in appearance of cloth from its loom state wrought by milling and raising (two colors are used to show the changes better)

The answer emerges that the papermakers utilize almost every worth-while property of the woolen felt in pressing—from the submolecular segments of the protein molecules through the molecules, the subfibrillar features, the fibers themselves, the yarn spinning and weaving structures, right up to the properties imparted to the felt in the finishing operations. To illustrate this statement in a little more detail, let the various steps enumerated be considered successively.

Submolecular Features

The protein molecule of the wool consists of long, folded chains, linked together, at right angles, by two main types of side chains: (a) the cystine link R—CH_2—S—S—CH_2—R and (b) the salt link, R—$COO^- \dot{H}_3N$R as shown in Fig. 12 (*6*). As most papermaking is done on the acid side of neutrality, the cystine linkage and the main chain provide the stability of the fiber in an acid medium for long periods in contrast with, say, cotton which would hydrolyze and disintegrate under the same conditions. The function of the salt linkage is more subtle. As has been seen in the analysis, it is necessary for a wet felt to have a high degree of compressibility in the wet. The salt link is broken in acid media, thus increasing the degrees of freedom of the molecule and is one of the bases for rendering the wool molecule—and fiber—rheologically to approach the ideal required in wet felt, i.e., an ability to undergo, repeatedly, large strains relatively easily followed by complete recovery when the stress is removed. Another basis is the molecular structure itself which permits large-scale recoverable deformations.

Molecular Feature

The long polypeptide chain of wool keratin can be represented as shown in Fig. 13 (*7*) with the side links shown in Fig. 12 at right angles to the plane of the fold.

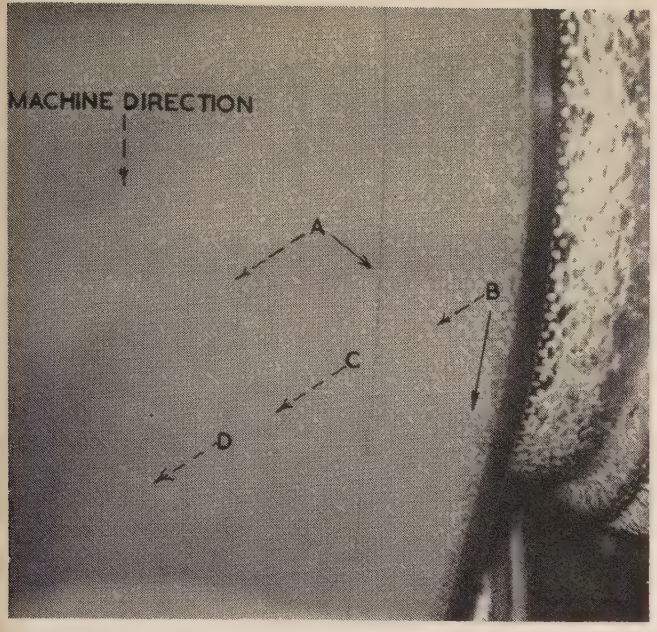


Fig. 9. A high-speed flash photograph taken by B. H. Browning of the Bowater Paper Corp. Ltd., London, showing the state of the sheet at the couch of a newsprint machine

This heavily folded configuration—or similar ones, e.g., helical (*8*)—coupled with the acid-sensitive salt linkages and acid resisting cystine group give a molecule which under relatively small stress yields very large strains, but which at the same time recovers fully on the stress being removed (see also Fig. 1). The felt is rendered capable of high compressional strain in the wet, acid state followed by remarkable recovery on stress removal. Thus, this vital property for wet felts is fully met by the molecule and its different parts.

Subfibrillar Feature

Figure 14 shows the appearance of the fiber surface under the microscope as represented by a model magnified 2000 times. The surface is covered with imbricated scales pointing from the root toward the tip. The coefficient of friction from root to tip is smaller than from tip to root. Consequently, the fiber moves more readily in the direction of the root than in that of the tip. This directional frictional effect together with the ability of the fiber to yield high strains under stress and complete recovery afterwards gives rise to the felting property of the wool fiber (*9*). It means that a wool fiber will, say, under compression, travel into the interior of a fiber clump, stretching afterwards without breaking when the compression is released, and completely relaxing on the next compression by further movement. Thus, the fiber will be anchored in the body of the felt while a soft yielding nap performs the other functions required from the felt. This liveliness and continuous motion of the wool fiber also contributes to the dirt-shedding propensity of wool felts.

Fiber Features

The wool fiber has a varying amount of crimp and the finer the fiber the greater its crimpiness. This fact makes the fiber "soft and flexible"—i.e., yielding to compression and elastically resilient. The surface of the felt is thus in the right state to apply an even pressure without marking the wet delicate sheet and yet is open enough for water transport.

Yarn Spinning Features

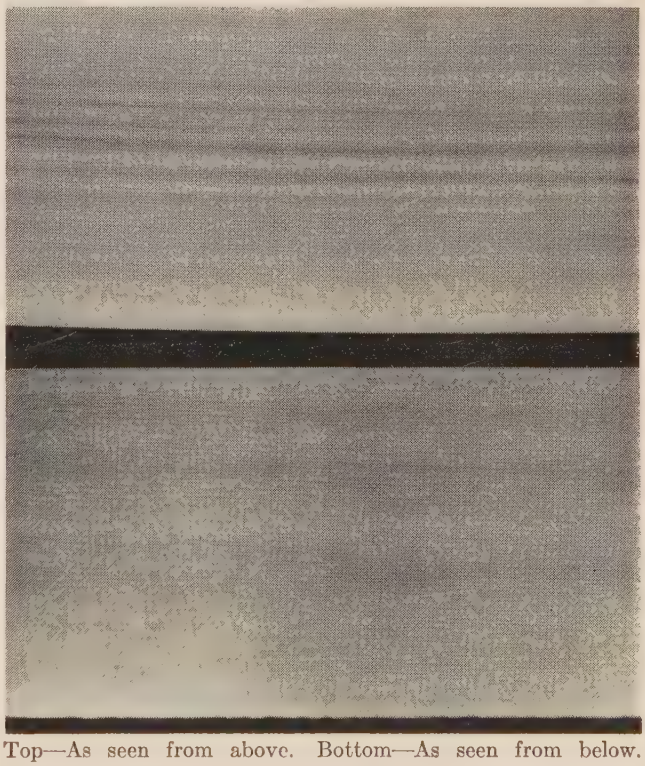
The softness required in the surface is enhanced by the felt manufacturer. Of the several systems of spinning, it is generally known that spinning on the mule yields the softest yarn of a given strength or, conversely, the strongest yarn for a given hardness of twist. Some manufacturers use mule-spun yarn for both weft and warp while others use only mule-spun yarn for the weft thread since the weft is used for the surface cover; where extra softness is required sateen weave is adopted.

Weaving Features

The wet felt must combine a soft nonmarking surface (which implies a close texture) with an open structure to allow maximum ease for water to flow. This combination of properties is attained by the manufacturer by choosing his weave structure (usually an irregular sateen weave) and finishing correctly so that the "cover" is provided mostly by the soft weft and the high permeability by disposition of the warp and weft relatively to each other.

Finishing Features

The woolen felt, after weaving, is "milled" or shrunk, sometimes by as much as 50% on the loom width of the felt, by subjecting the felt to repeated compression and relaxation in a wet state. The peculiar properties of the wool fiber already briefly described cause it to migrate and intertwine and thus an



Top—As seen from above. Bottom—As seen from below.

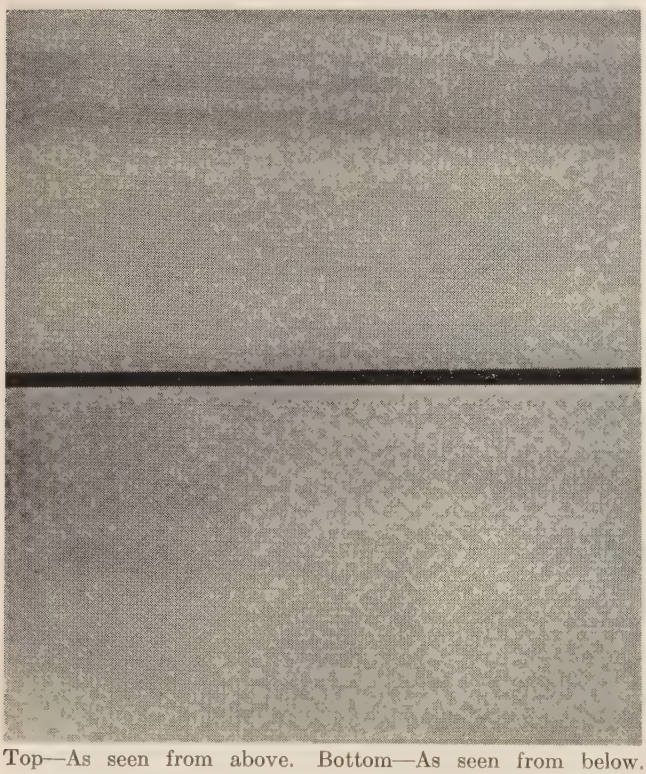
Fig. 10. A high-speed flash photograph taken by B. H. Browning of the Bowater Paper Corp. Ltd., London, showing the state of the sheet after it has passed through a solid press nip of a newsprint machine, as seen from above and from below the sheet

elastic, soft, spongy felt is produced. The fibers are also raised at the surface to give a soft nap on which the sheet may rest without injury during pressing. Chemical treatment of the fiber and felt is given in the finishing operations to increase resistance to bacterial or moth attack or to increase resistance to mechanical abrasion forces.

It will be seen that at every stage the papermaker and feltmaker are utilizing specific properties of the fiber and its manipulation and modification to make the felt the most useful piece of equipment that can be made for the purpose. The result is a soft, bulky, highly elastic compressible cloth, durable in the wet, slightly acid conditions and of high water permeability and dirt shedding qualities.

FUNCTIONS OF FELTS IN REMOVING WATER IN THE DRIER SECTION

In multi-cylinder drying, the sheet undergoes a number of cycles of heating followed by evaporation and cooling. If a "cycle" is considered to begin with the point when the sheet first touches a cylinder and to end when it first touches the next cylinder, there will be four unequal phases in each cycle: (1) In the first phase the paper sheet is in contact with the cylinder on one side, the "inner side," and with the atmosphere on the other or outer side. (2) In the second phase, the felt is in contact with the outer side while the cylinder is still contacting the inner side. (3) Next, the felt leaves the sheet and the paper once again contacts the hot cylinder on the inner side while free air is on the outer side. (4) In the last phase the sheet is in contact with air on both sides.



Top—As seen from above. Bottom—As seen from below.

Fig. 11. A high-speed flash photograph taken by B. H. Browning of The Bowater Paper Corp. Ltd., London, showing the state of the sheet after it has passed through the nip of a suction press, as seen from above and from below the sheet

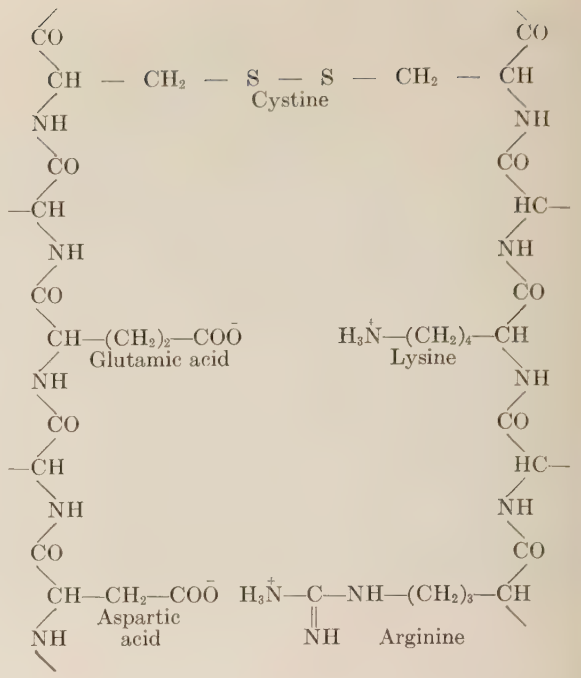
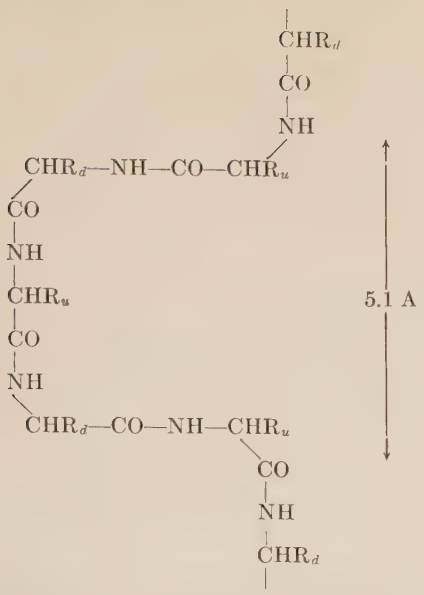


Fig. 12. Constitution of the wool chain (after Speakman)

In each of the four phases a different rate of heat and mass transfer applies. Thus, even phases (1) and (3), which are similar because in both the sheet is heated on one side while water is evaporating more or less freely on the other, differ in three respects, viz., the sheet is colder in (1) than in (3), it is in less good contact with the cylinder in (1) than in (3) and aerodynamically they are different too as in one the sheet moves into and in the other out of a confined space. It is only in phase (2) of each cycle that the felt exerts a direct influence on the rate of loss of water from the sheet. Authorities appear to be almost unanimous, with the significant exception of Professor Sherwood (*10*), that the major effect of the felt is to improve the rate of heat transfer by improving the contact between the sheet and the cylinder. On this basis the drier felt appears to need no particular study insofar as water removal is concerned. Thus, in recent exhaustive treatments of felts the principal requirements in a cotton drier felt were considered to be: (1) a smoothness of surface adequate for the type of paper being produced; (2) a strength sufficient to withstand the tension applied to the felt; (3) a flat surface and even cross section, and (4) a good dimensional stability. No special properties of the felts are specified as being *directly* required for water removal and it would appear the drier felts are purely mechanical devices for exerting pressure on the sheet. If the facts were so, they would be disappointing for two reasons, the second of which is believed to be the more important:

(1) When considering wet felts the questions were asked "Why wool?" and "Why, indeed, felts?" The answers revealed quite a number of reasons *directly connected with the mechanism of water removal.* To the questions "Why cotton?" and "Why, indeed, felts?" there would be an equally convincing array of reasons; but they would not be *directly* connected with the mechanism of water removal.



(The subscripts u and d signify that the side chain (R) is pointing up or down, respectively, from the plane of the fold).

Fig. 13. The "shape" of the wool molecule (after Astbury)

(2) A far more important cause for dissatisfaction with the state of affairs—at least, insofar as the author is concerned—would be the following. There appears to exist a mechanism for the speedy removal of water—*in the liquid state*—from the web into the felt in the early cycles of the drying section. If this mechanism is inactive in a paper machine then it appears that the machine is possibly not utilizing a process which may have increased the rate of water removal and consequently the output of the machine.* To amplify these statements, it is necessary to show (1) the nature of the mechanism envisaged for water removal in the liquid state; (2) any evidence that such a mechanism has, in fact, ever been observed; (3) the steps to be taken in order to utilize such a mechanism on a paper machine.

Let a sheet with (say) surface temperature of 100°F, in an atmosphere at (say) 80°F., approach and contact a cylinder with a surface temperature of (say) 220°F. Both the cylinder and the sheet will carry a boundary layer of air with them. The boundary layer will have a temperature gradient; the one in contact with the sheet will drop from 100°F. at the sheet surface to 80°F. at the outer surface, while that in contact with the cylinder will drop from 220 to 80°F. For simple calculations the two boundary layers will be assumed to be equal in thickness and to possess linear temperature gradients. Thus, the sheet layer will have an average temperature of 90°F. while that of the cylinder, an average of 150°F. The mean temperature of the air separating the sheet from the cylinder at contact is, therefore, 120°F.

At the end of the third phase—i.e., when the sheet is about to leave the cylinder, the temperature of the sheet and the air have both increased. Under suitable conditions of heat transfer and time of contact the sheet may reach a temperature of (say) 150°F. The boundary layer will now be at 150°F. on one side and approximately 220°F. on the other with an average temperature of approximately 185°F. Thus, the boundary layer has increased by 65°F.

If the sheet is not pressed tightly, the air will expand by (65/579) of its original volume or by just over 11%. Conversely, if the sheet is so rigidly held that the air is not allowed to expand, the pressure would increase by just over 11% of an atmosphere, say, 1.7 p.s.i. In fact, however, the sheet is neither free to move away from the cylinder—because of felt tension—nor has it got a rigid surface as the water in its interstices will move outward under pressure. Thus, a felt tension of, say, 10 lb. per linear in. on a 5-ft. cylinder will exert 0.33 p.s.i. pressure. This means that the boundary layers will expand by some 8% in volume and simultaneously exert a differential pressure across the sheet of 0.33 p.s.i. Thus, the wet, hot sheet of paper is being subjected to a head of some 9 in. of water tending to push the water from the sheet into the felt. (It should be noted that without a backing of air which can expand and take the place of the water, the felt cannot absorb the water without disrupting the sheet by the vacuum that would be created behind or in the sheet.) The sheet is of some 0.005 in. thickness, only some 0.003 in. of which is water, so that even a movement of liquid averaging only 0.0003 in., due to the 9-in. head acting for the time of contact, will actually

Courtesy of the International Wool Secretariat, London

Fig. 14. Model of a merino wool fiber showing cellular structure and scales on the surface pointing toward the tip

* In discussing this matter. E. Race informed the author by private communication that the transfer of liquid water from sheet to felt was, in fact, envisaged by him too. The author has also learned, since writing this paper, that in a recent private publication A. E. Montgomery holds the same ideas.

remove 10% of the total water carried by the sheet in a single cycle. If the sheet enters the drying section at 67% moisture content, it should drop to 64% by this mechanism alone. If time of contact is even as high as 0.5 sec., then for a machine making news at 50 grams per sq. in. this rate of water removal implies a water loss at some 14 lb. per sq. ft. per hr., calculated on the paper dried. This compares favorably with the 2 to 3 lb. per sq. ft. per hr. usually obtained.

The figures chosen appear to be not unreasonable, except perhaps the average movement of 0.0003 in. of water arbitrarily chosen. But even if only one tenth of this movement were assumed—a small quantity compared with the thickness of the fibers of either paper or felt, the scale of dimensions which may be taken to rule in that field—the rate of water removal by this mechanism of hot pressing should be considerable. Furthermore, from a purely physical and qualitative viewpoint, there does not appear any reason to doubt that the felt—if it were in a state to receive the water—should act as an absorbent sponge but with the advantage over the ordinary press felt of working at much higher temperatures and for longer contact periods. The absence of such a mechanism in any paper machine must, therefore, imply that the felt is not in a state to receive the water. Before discussing the conditions necessary to render the felt in an ideal state for operating this mechanism, it is reasonable to ask if there is any evidence that such a mechanism has ever been observed in practice.

It was argued that one reason why not a great deal is made of this mechanism must be that felts approach the cylinders in too water-logged a condition; another, of course, is that the felts are not made for that purpose. Therefore, it was decided that if such a mechanism is to be observed, it should be searched for among slower machines, which allow the felt more time to dry on their return journey.

In 1938, Sherwood (*10*) and his colleagues at M.I.T. studied experimentally the drying of paper on a multicylinder machine running at 366 f.p.m. In this, now classical, study Professor Sherwood and his co-workers discovered that the amount of water accounted for by evaporation into the air was no more than 20% of the total loss of water. After very careful analysis of the results, it was concluded that the state of the felt was of primary importance and it was suggested that the water either passed bodily into the felt or that it was evaporated and recondensed in the felt. While this latter mechanism of evaporation into the felt has to overcome certain difficulties before it can be accepted, since not enough evidence supporting the hypothesis of water loss by liquid absorption was available, it had to be accepted as a legitimate alternative. Nonetheless, this important work served as a signpost to the type of finding which, if coupled with other data, may establish the existence of the hot pressing mechanism. A more recent work by Attwood and Smith (*11*) and Smith and Attwood (*12*) immediately gains in significance for they too have rediscovered the same phenomena but, in their work, they also provide certain other data which have proved most useful.

Smith and Attwood again confirmed that some 80% of the water loss occurs when the sheet is in contact with the felt. They have tentatively accepted the mechanism to be evaporation into the felt followed by condensation in it.

What Smith and Attwood have established can be summarized in a little more detail as follows:

(1) Wet paper sheets evaporating in a stream of air follow well-established laws.

(2) When wet sheets are dried by being first pressed against hot metal surfaces by felts and then allowed to dry freely in air, the water loss does *not* follow established principles in that:

(a) There is no well-established region of constant rate of drying followed by falling rate; the rate falls from the beginning.

(b) Changing the conditions of air produces none of the expected changes in the rate of drying.

(c) Only changes in conditions of the felt or the frequency of contacts between felt, paper, and metal, effect notable changes in the rate of evaporation, i.e., the rate increases as the pressure increases; the rate increases as the number of contacts made per unit time increase; the rate increases as the permeability of the felt increases.

(d) The rate increases linearly with the temperature.

Clearly, the observations can be qualitatively explained either on an evaporation or a liquid absorption mechanism. Quantitatively, it is difficult to see how the felt can provide conditions of evaporation totally unrestricted by the presence of the felt, the resistance of which to *air*—not water vapor, necessarily—is usually of the order of 500 times that of a free unrestricted orifice of the same size. On the other hand, it is possible to predict at least, approximately, the type of behavior to be expected quantitatively if the liquid is absorbed by a flow process. Incidentally, Smith and Attwood (*12*) have noticed the fact that "drying rate is considerably increased by high felt tension, especially during the early part of the drying, the advantage being maintained—rather than increased—in the later stages." This observation and the parenthetical phrase appear to support the water absorption hypothesis a little more than the evaporation/condensation postulate.

If liquid water is being forced into the felt, it has already been established that the total distance moved must be extremely small. Thus, the regime of flow must be considered as that existing at the mouths or entries of capillaries—*not* capillary flow. Several attempts have been made for deriving the laws of flow obtaining (*13*) at entries and while there is some disagreement upon the exact value of the constant A in the equation, it is agreed by all that equation (6) satisfies the conditions.

$$\Delta P = A \rho v^2 \qquad (6)$$

where

ΔP = pressure loss at the entry or "inlet length" of a capillary
ρ = density of liquid
v = mean velocity of liquid
A = a constant, most probably = 1.14

Thus, if the weight of water per pound of dry paper in the web is denoted by W, then the water loss per cycle $(\delta W/N)$ may be given by (7)

$$(\delta W/N) = \delta W_1 + \delta W_2 \qquad (7)$$

where

δW = total loss of water (per unit weight of dry paper) observed in N cycles
δW_1 = that part of the loss due to mechanisms other than liquid absorption
δW_2 = that part of loss due to liquid absorption

For a machine working under constant conditions, except felt pressure, if equation (6) applies,

$$(\delta W/N) = \delta W_1 + f(W)P^{1/2} \qquad (8)$$

where

$f(W)$ = a function of the water content of the sheet and felt determining the facility with which water flows from the sheet into the felt

Equation (8) implies that (δW_1) is not affected by pressure. This is not strictly true, but for the purpose of the present discussion the influence of pressure on heat transfer and rate of evaporation will have to be assumed small compared with the liquid transfer mechanism. Thus, if equation (8) is true two statements should be true:

1. For a finite drop in water content between two fixed quantities, i.e., for a given (δW), $(1/N)$ the reciprocal of the number of cycles required, should bear an approximately linear relationship to the square root of the felt pressure (or tension since they are linearly proportional).

2. The slope of the "straight line" so obtained should decrease as the sheet gets drier. This, in fact, means $f(W)$ is not a constant, and that the "straight line" obtained will be found, on closer analysis, to be slightly curved.

Attwood and Smith (*11*) give the following table, slightly but not significantly modified in (*12*). Figure 15 shows that a plot of $(P^{1/2})$ vs. $(1/N)$ yields: (1) approximately straight lines, and (2) the slopes of the straight lines decrease as the water content of the sheet decreases. Thus, the two predictions—based on a simplified picture—of the liquid absorption hypothesis appear to be reasonably satisfied.

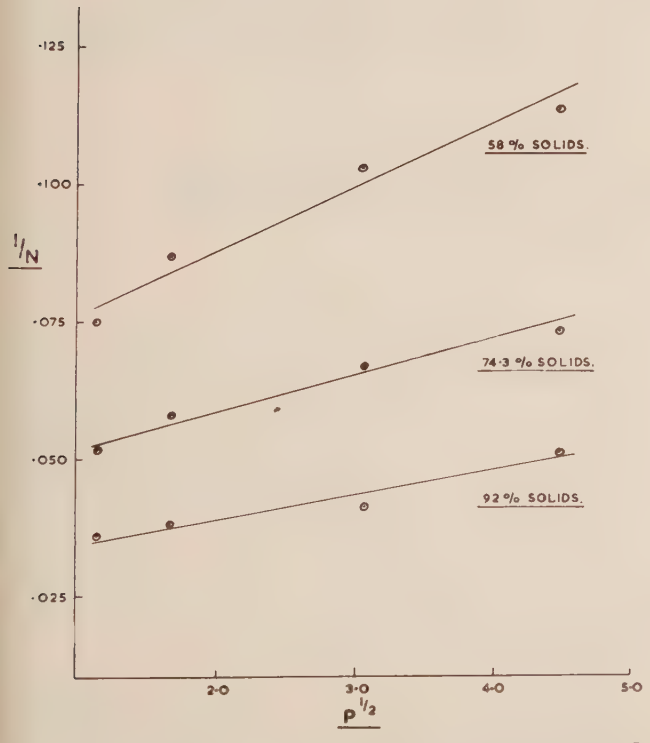


Fig. 15. The relation of P (the tension on the felt) and N, the number of cylinders required to reduce the water content of the sheet by a fixed amount is approximately linear when $(P)^{1/2}$ is plotted vs $(1/N)$

Table III

Felt tension, P, lb./in.	*Number of cylinders required to dry to 58% solids*	*74.3% solids*	*92% solids*
1.3	13.3	19.3	28.0
2.8	11.5	17.3	26.5
9.4	9.7	14.9	24.5
20.0	8.8	13.6	19.6

From the paper, it appears that the conditions of the machine were normally represented by a felt tension of about 9.4 lb. per in. The absorption contributed by the postulated mechanism may be represented by $(\delta W_2) = f(W)P^{1/2}$ against the total water loss per cycle $(\delta W/N) = \delta W_1 + \delta W_2$. Table IV gives some interesting results of calculations based on an initial water content of 63.4%. Thus, it appears that as much as 40% of the total water loss observed in the first 10 cylinders is attributable to a mechanism which depends on the square root of the pressure. By extrapolation, 60% of the total loss in the first five cylinders can thus be attributed to the pressure.

Table IV

Number of cylinders, N	9.7	14.9	24.5
Total water removed in lb. per lb. of paper, δW	1.01	1.38	1.64
Total loss per cylinder $(\delta W/N)$	0.10	0.09	0.067
Total attributable to the function $[f(W)(P^{1/2})]$	0.04	0.03	0.0153
$\frac{f(W)P^{1/2}}{(\delta W/N)} \times 100$, %	40	33	22

Clearly, some of the increase in the rate of water loss by increasing the tension must be due to improved heat transfer and evaporation. Nonetheless, the agreement between theory and observation makes it reasonable to assert that, at least, in the first few cylinders of the machine where evaporation must be small by any mechanism, liquid absorption by a hot pressing operation probably operates when conditions are favorable.

If this hypothesis is accepted two questions arise: (1) Is it desirable to enhance such a mechanism? (2) If so, how can that be done?

If the mechanism operates, the rate of water removal from the sheet is increased. On the other hand, unless the water is removed from the felt as fast as it is absorbed, the absorption must, ultimately, cease. The advantage, therefore, can only be maintained if the water is removed either at a faster or at a cheaper rate—or a combination of both—from the felt than is possible with the sheet by evaporation alone. This is a problem for the paper machinery designers, but it is suggested that an advantage may be gained by utilizing (1) the long free run of the felt on its return journey which should increase the total evaporation area available; (2) by utilizing air blown *through* the felt, a process inapplicable to the drying of the sheet, to increase the rate of evaporation, and (3) by utilizing flue gases to dry the felt before it returns to the sheet (via heat exchange with the air blown through the felt)—again a process which cannot be applied so readily to the sheet.

Finally, what are the conditions for operating this mechanism to its maximum or optimum extent? There are several deductions possible:

1. The drier felt for the first section should be designed with this mechanism in mind. The top surface should be like a press felt, but since the water is not removed from the felt by compression there is the further consideration that the lower surface should facilitate evaporation. Thus, the felt should be a compound cloth with fine, good woolen or nylon (especially "textured" nylon) nap surface on the paper side and smooth textured, say, wool (if the top is woolen as otherwise there would be difficulties in milling), nylon, terylene, linen, or cotton, open weave structure on the other side. In this way both ease of liquid absorption on the paper side and ease of evaporation on the other side are designed for.

2. The felt should be returned in a dry hot state to the cylinders. This can be done by greater use of inter-cylinder driers than obtains at present. If this is not possible on old machines, it may be found possible to improve the rate of drying by using, say, every third cylinder in the first section or two for felt drying, the paper sheet by-passing these cylinders.

3. By blowing air over the felts as they pass over the felt rolls between cylinders.

4. By blowing air through the felts—preferably but not necessarily preheated air.

CONCLUSION

A warning was issued at the beginning of the paper that, no matter how one tries, observation, interpretation, and speculation tend to intertwine into an exceedingly complex structure which is most difficult to disentangle. Some attempt was made, at least to keep the three distinctly in focus. It is feared, nonetheless, that with the functions of felts in drying, speculation won the day—as sometimes, it is said, a character in fiction wins the mastery over his author. Even then, however, it is hoped that what is speculative is distinguishable from what has been observed. So long as the hypothesis proposed and recommendations made are not mistakenly read as observations of facts, they may be useful in at least promoting a desire to give an answer to "Why drier felt?" as satisfying, from the viewpoint of drying paper sheets, as the answer to "Why woolen felts for pressing?"

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Effects of Wet Pressing on Sheet Properties

D. J. MacLAURIN and J. F. WHALEN

Relationships between wet pressing and dry sheet strengths are reviewed. Experimental work is presented relating pressure, number of pressings, pulp freeness, and dry sheet properties for unbleached Douglas-fir kraft handsheets.

THROUGH the long centuries when paper was made by hand, one of the steps in the art was to give the wet web a pressing between felts before the sheet was hung up to dry. The first paper machine, as invented by Louis Robert, included a pair of squeeze rolls or wet press, which removed water from the freshly formed wet web as it passed through the nip on the endless wire belt. Today, practically every papermaking sequence includes wet pressing.

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The early papermakers pressed their freshly couched sheets for several reasons. Pressing between felts expelled water from the wet web, thus making it strong enough to be handled. Removing water by pressing lessened the time the sheet had to hang in the drying loft, and, too, pressing the wet sheet improved the finish and texture of the dry sheet. These reasons for wet pressing are still valid and inclusive. Thus, the economics of water removal and the properties and qualities of both the wet and the dry sheet are each and inseparably related to wet pressing.

Wet pressing is therefore an important operation in the papermaking process. It removes water from the wet web and plays a part in determining the properties of the finished sheet. It also has some influence on the behavior of the sheet during drying and other operations such as smoothing, on-machine sizing and coating, and

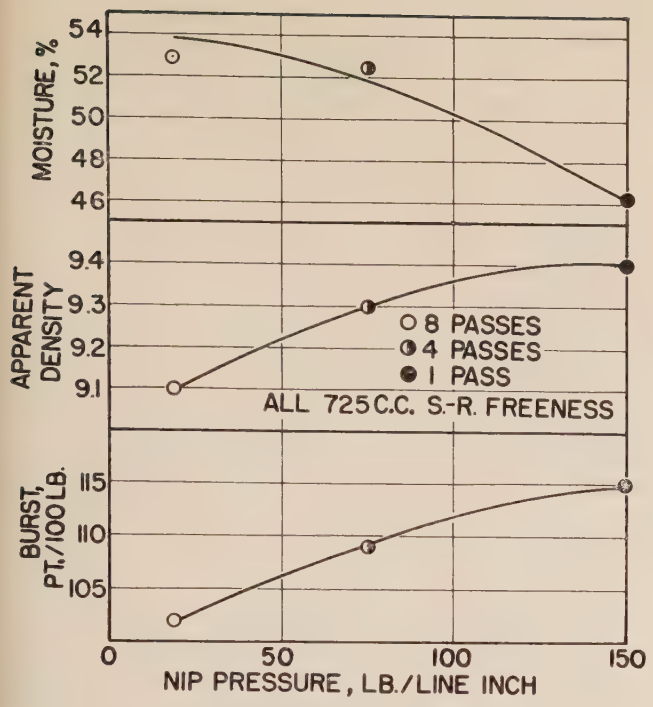

Fig. 1. Effect of number of pressings and pressure on sheet properties

calendering. For purposes of this discussion, wet pressing is to be understood as the pressing given a wet sheet after it leaves the wire or mold and before it enters the drier section. This definition of wet pressing which confines it to the usual wet end press section, thus excludes other typical papermaking operations such as the removal of water by various means on the wire, the rewetting and pressing of the sheet at size and coating presses, and by sweat driers, sprays, or wet boxes, before or at the calenders—all of which might be included in a broader definition of wet pressing.

A typical fourdrinier sheet enters the wet press section at about 16 to 20% solids and leaves at about 30 to 35% solids, after having passed through two presses. General considerations, supported by calculations based on the thickness and moisture content of the sheet, lead to the conclusion that within this range of moisture contents, the web is composed of water and fiber only. It is a liquid-solid system in which the solid is relatively uniformly dispersed as discrete particles throughout a continuous liquid phase. As the wet web passes through a press nip it is subjected to increasing and then decreasing pressure. Pressure gradients are established in the liquid phase which cause water to flow, some of which leaves the sheet. Normally the sheet is pressed against a felt or between felts which have a capacity to take up water forced from the sheet. As the water leaves, the fiber mass is compacted and the fibers are brought into more intimate contact, thus providing a better opportunity for development of fiber-to-fiber bonding. This brief description of water removal in the wet presses obviously omits consideration of many important phenomena and involved relationships. These have been discussed by Campbell (*1*), Ingmanson (*2, 3*), and others. It is the purpose of this paper to consider the relationships between wet pressing and the properties of the dry sheet.

The effects of wet pressing on sheet properties have been of interest for some time. Early patents (*4, 5, 6*) dealing with the use of preheaters between pressing stages claimed improved water removal but also claimed that the dried sheet was stronger and had improved feel and surface. In the early thirties, at the U. S. Forest Products Laboratory, Doughty (*7–10*) and Chilson and Baird (*11*) made an extensive study of relationships between wet pressing of handsheets and the properties of the dried sheets, using unrefined spruce sulphite pulp. They showed that dry sheet density, tensile, fold, and burst increased with increasing pressure. In another phase of this study, Doughty (*10*) separated the pulp into various length fractions by wet screening and showed that at the same wet pressure, sheets of shorter fibers were denser and had higher tensile strength than sheets of longer fibers. The amount of shrinkage which took place as the sheets were dried increased rapidly to a maximum at relatively low pressures, then decreased with further increase in wet pressure. Sheets from short fibers showed greater shrinkage than those from long fibers at any particular pressure. These studies by Doughty lead to the broad generalization that wet pressing has the same kind of effects on dry sheet properties as typical refining. There is the obviously important difference though that the drainage characteristics of the pulp slurry are not affected by wet pressing while they are by refining. Probably though, the drainage characteristics of a wet sheet which has had some wet pressing are determined in part by that wet pressing.

Annergren (*12, 13*) studied the effect of beating and wet pressing on the swelling power of handsheets of both sulphite and sulphate pulps in 18% caustic solution. In that work, swelling power was defined as directly proportional to the increase in the weight of a sheet after immersing it in the caustic solution for 10 min. at 20°C., then removing and draining the sheet for 2 min. In this work he showed that handsheet swell-

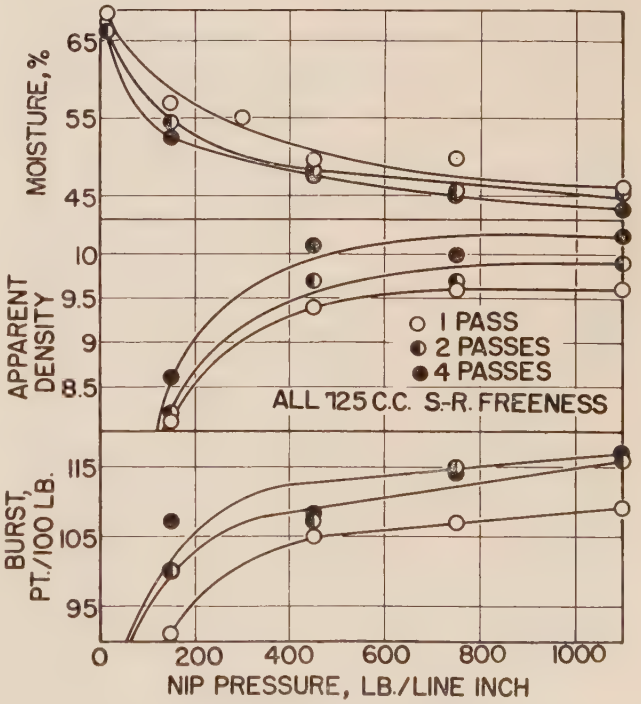

Fig. 2. Effect of number of pressings and pressure on sheet properties

ability increased and then decreased as beating progressed. If wet pressing pressure was increased, the same maximum swellability was reached with less beating. While no direct relationships between swellability and strength were established, Annergren noted that the effects of wet pressing on strength were greater when beating had not proceeded beyond the point of maximum swelling. He associated increase in swellability with increase in "hydration" and the subsequent decrease in swellability with the occurrence and increase of fibrillation. Thus, in general, the concept of an interaction between degree of refining, wet pressing, and dry sheet properties is introduced. There appears to be an optimum amount of refining for maximum gain in dry sheet strengths as a result of wet pressing. This would seem to be a very reasonable concept, particularly if the role of wet pressing is envisioned as bringing fibers into more intimate association, thus assisting bonding between fibers due to capillary forces, as is so convincingly discussed by Campbell (*14–16*). If the fibers are sufficiently flexible and fibrillated, bonding is not increased by wet pressing.

Lindman (*17*) made an extended study of the strengths of a sheet at points along a paper machine drier section. He concluded that excessive wet pressing could give a lowering of dry sheet strengths. While undoubtedly if wet pressing causes crushing, the dry sheet will be relatively weaker, it appears possible that in this study the effects of the strongly related variables of wet pressing and stretch may not have been distinguished and thus weakening assigned to wet pressing should more correctly have been assigned to draw and associated stretch. Lindman found that the sheet had a higher fold and density immediately after the wet presses than after the first few driers, which suggested the possible importance of interaction between amount of wet pressing, rate of rise of sheet temperature during drying, and dry sheet strengths.

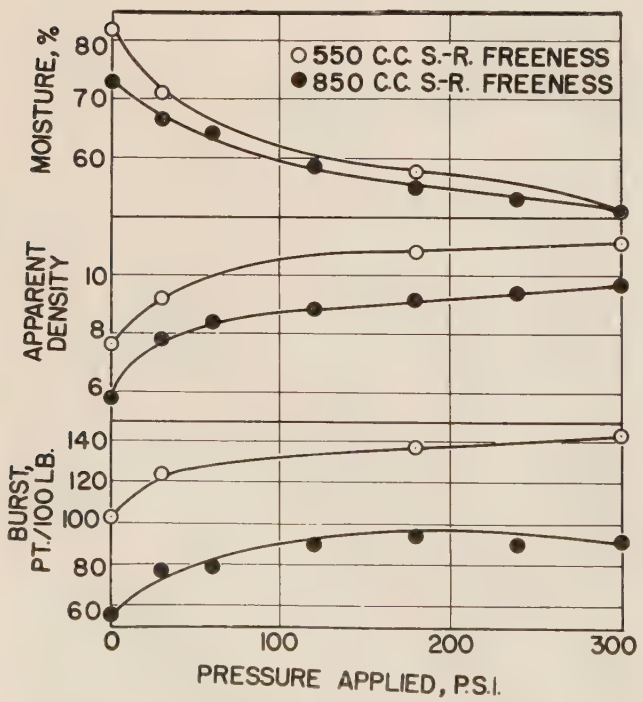

Fig. 3. Effect of pressure and freeness on sheet properties

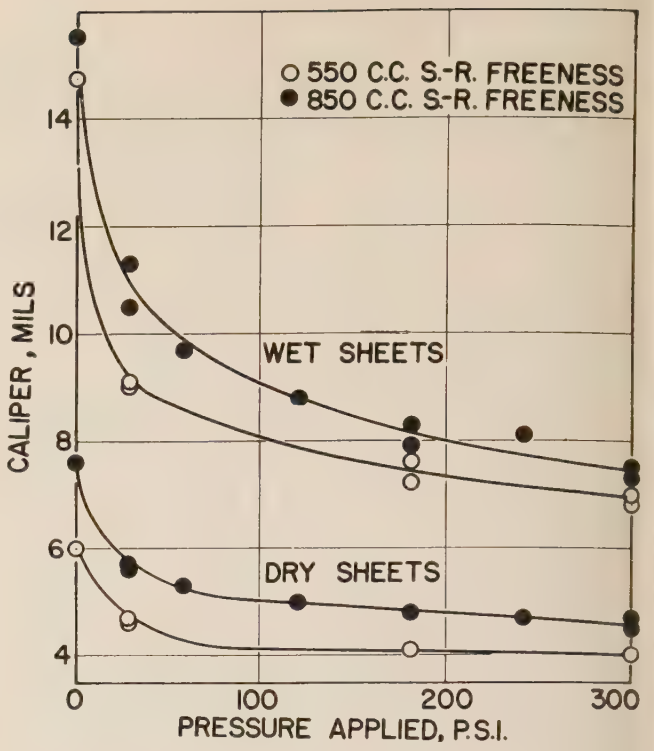

Fig. 4. Effect of pressure and freeness on sheet caliper

Arlov and Ivarsson (*18*) showed how stretch could counteract the effects of wet pressing.

Relationships between some rheological properties of wet sheets and dry sheet strengths were studied by Seborg, Simmonds, and Baird (*19*). They showed that as refining increased, equilibrium wet sheet density under pressure was approached decidedly more slowly, and conversely, equilibrium sheet density after pressing was reached slightly more quickly as the amount of refining increased. The equilibrium sheet density under pressure was largely independent of degree of refining, but the wet sheet density after pressing decreased with refining. While these studies were directed at pulp evaluation techniques, they also raise some questions in connection with the effects of wet pressing on dry sheet properties. The rheological behavior of wet sheets directs attention to the possible importance of the amount of time the wet sheet is retained under pressure, and the time between successive pressings. Perhaps for accentuated effects of wet pressing on dry sheet strengths (and water removal) there would be merit in equipment which gave more time in the press nip. As we would not normally choose to achieve this by slowing the machine down, it may be that longer nips are needed. Perhaps these could be obtained through pairs of very soft rolls or pairs of belts running in flat elliptical paths.

The general relationships between wet pressing and dry sheet properties were discussed briefly by Forman (*20*) who drew attention to the possibility of limited replacement of refining by wet pressing in developing sheet strengths. In a recent series of papers on the fundamentals of papermaking, Fiebiger (*21*) briefly considers relationships between wet pressing and the ratio of cross and machine direction strengths. In this connection, a recent patent by Cluett (*22*) discloses a method in which the wet sheet is compacted in the

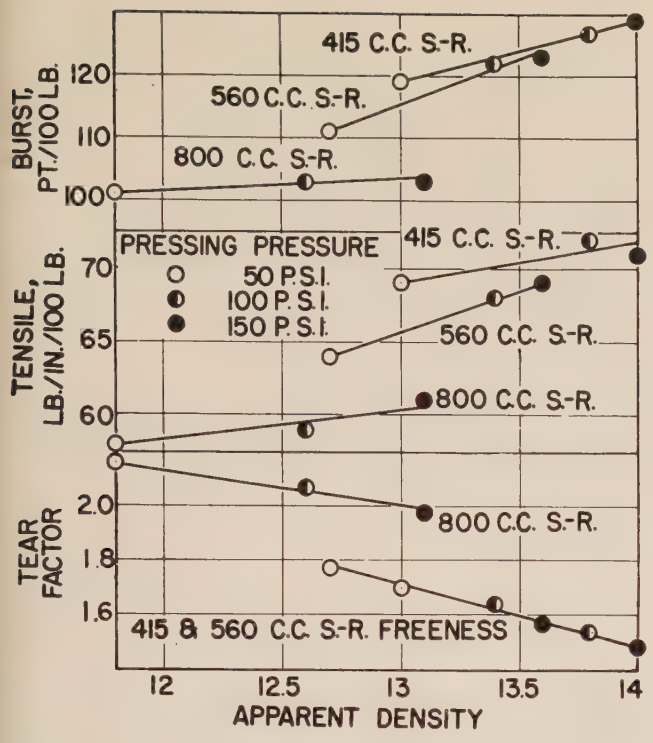

Fig. 5. Effect of pressure and freeness on sheet properties

machine direction as it passes through a long nip in which there is a speed differential between each half of the nip. No numerical data appear to be available, but there are some striking claims of the effects of this kind of wet pressing on dry sheet properties.

EXPERIMENTS WITH UNBLEACHED DOUGLAS-FIR KRAFT

It is known that unbleached Douglas-fir kraft sheets have a relatively high tear. Under certain circumstances it would be advantageous to increase the bursting strength of these sheets. This of course could be done through additional refining at the expense of tear and drainability. Because of the general relationships between wet sheet pressing and dry sheet strengths it was predicted that the dry sheet burst of Douglas-fir kraft could be raised by additional wet pressing alone, thus avoiding slowing the stock through refining. The following experimental details and results are selected from a program which was designed to establish some of the quantitative aspects of that prediction.

Commercial unbleached Douglas-fir kraft pulp was used in all the work. Laboratory refining was done in a 1.5-lb. Valley beater, using 6500 grams on the bedplate arm.

Except for the experiments illustrated by Fig. 5, all handsheets were made on an 8 by 8-in. Noble & Wood handsheet mold to a 40-lb. 24 × 36—500 basis weight. Each sheet was couched onto a wet blotter, applying vacuum while couching. This procedure gave a sheet of about 27% solids. Sheets were pressed in various roll and flat bed presses under various loads and conditions. The pressed sheets were stripped from the blotters and dried by two passes through a Noble & Wood rotary drier at a surface temperature of about 190°F. and 1.5 min. per pass. After drying, the sheets were conditioned at 73°F. and 50% R.H., then tested for basis weight, caliper, bursting, tearing, and tensile strengths by TAPPI procedures. The data for Fig. 5 were obtained from standard TAPPI handsheets and procedures, except that wet sheet pressing was not standard.

In considering wet pressing on a typical fourdrinier machine, obvious questions are: how many presses and what load at each. Figures 1 and 2 show some relationships for laboratory-refined pulp at 725 ml. Schopper-Riegler freeness. The pressing in Fig. 1 was done between a pair of 3-in. steel rolls at a sheet speed of 5.7 f.p.m. and in Fig. 2 between 12-in. steel rolls at 44 f.p.m. Dry blotters were used at each pass above and below the wet sheet on the couch blotter. These experiments indicate that repeated pressings at lower pressures are not as effective in raising burst as a single pressing at higher pressures. From Fig. 2 it appears that there is a maximum effect beyond which more passes and higher pressures give little added improvement. Figures 3 and 4 illustrate experiments made on laboratory-refined pulp at two freeness levels in a flat bed press where maximum pressure was reached in $^1/_2$ min. and held for 5 min. The sheets were pressed in stacks of 6—each sheet between blotters. The data in Fig. 3 indicate that gains from pressing can be obtained at both 850 and 550-ml. Schopper-Riegler freeness. However, the level of an effect at a pressure is definitely dependent on freeness. As in Fig. 2, the curves in Fig. 3 show a maximum effect level which is not raised by increasing pressure. Figure 4 offers a possible explanation for this maximum effect. It appears that a sheet can be compacted so far and no further, unless perhaps very high pressures are used which are sufficient to crush the fibers and remove internal water.

The experiments illustrated in Fig. 5 extend the study of the interrelationships between refining, pressure, and sheet properties. These data were obtained using TAPPI handsheets and press. It is interesting to note that sheet density-strength relationships are

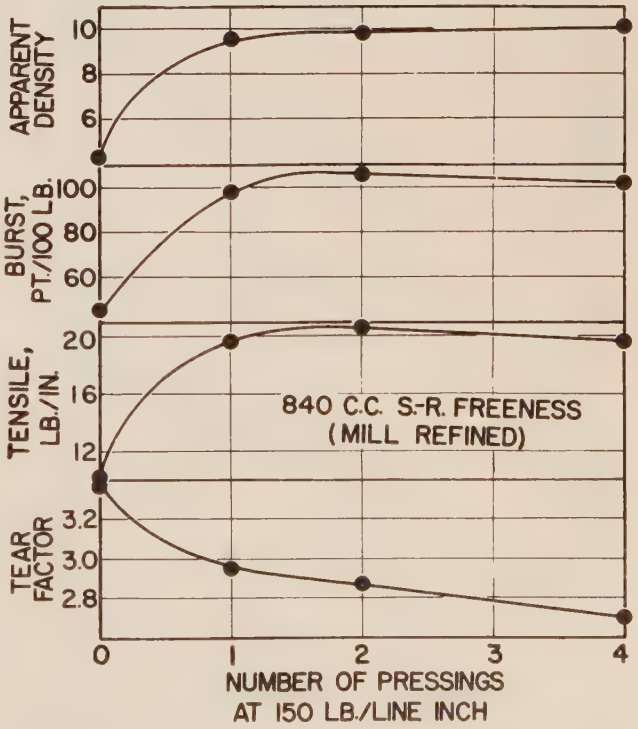

Fig. 6. Effect of number of pressings on sheet properties

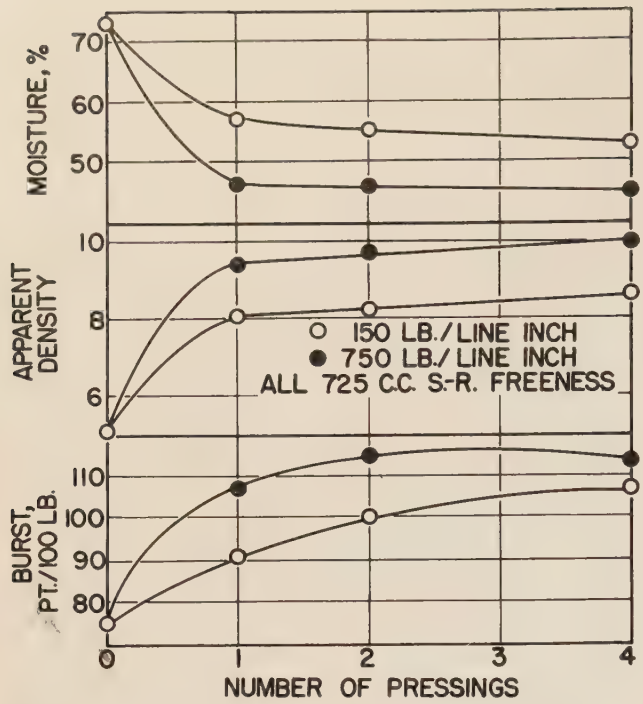

Fig. 7. Effect of number of pressings and pressure on sheet properties

not independent of refining. It is quite apparent that refining is more effective than wet pressing in raising burst.

In the course of these experiments it seemed well to check some of the conclusions reached on laboratory-refined pulp, using handsheets made from mill-refined pulp. The data in Fig. 6 were obtained on pulp refined in the mill to 840-ml. Schopper-Riegler freeness. The pressing was done between the 3-in. steel rolls. As expected, these data were in agreement with earlier

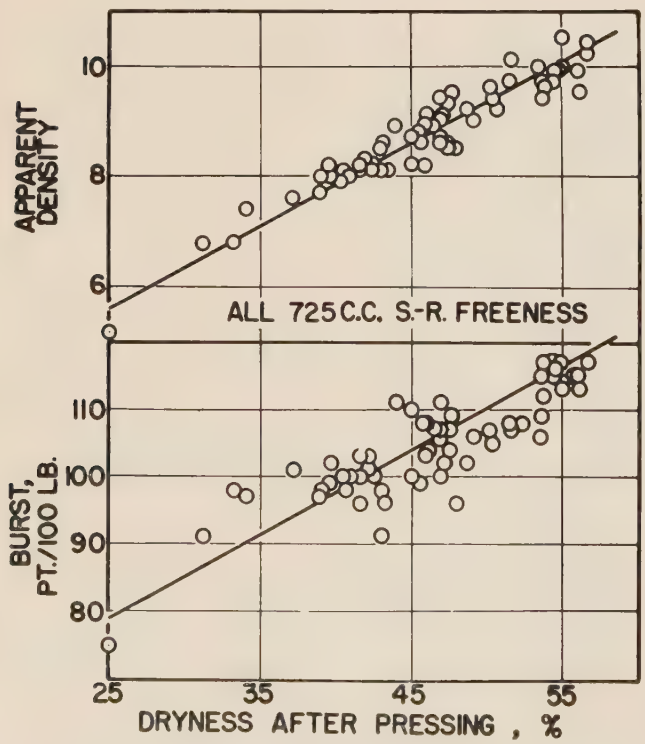

Fig. 8. Relationship between sheet dryness after pressing and sheet properties—laboratory-refined pulp

experiments and show the same leveling off of effects of pressing after two or three passes as noted in Fig. 2. The experiments shown in Fig. 7 were obtained on laboratory-refined pulp handsheets pressed between the 12-in. steel rolls. They further confirm the trends of limiting pressures and number of passes.

In Figs. 8 and 9 are plotted all the data obtained in the whole program for laboratory- and mill-refined pulps, respectively, relating dryness after pressing to bursting strength and sheet density. It is realized that many variables are thus lumped together; however, the rather high degree of correlation between burst and dryness after pressing indicates the strong possibilities of raising burst through wet pressing. The break in the curves of Fig. 9 again emphasizes the probable existence of a maximum level of gain.

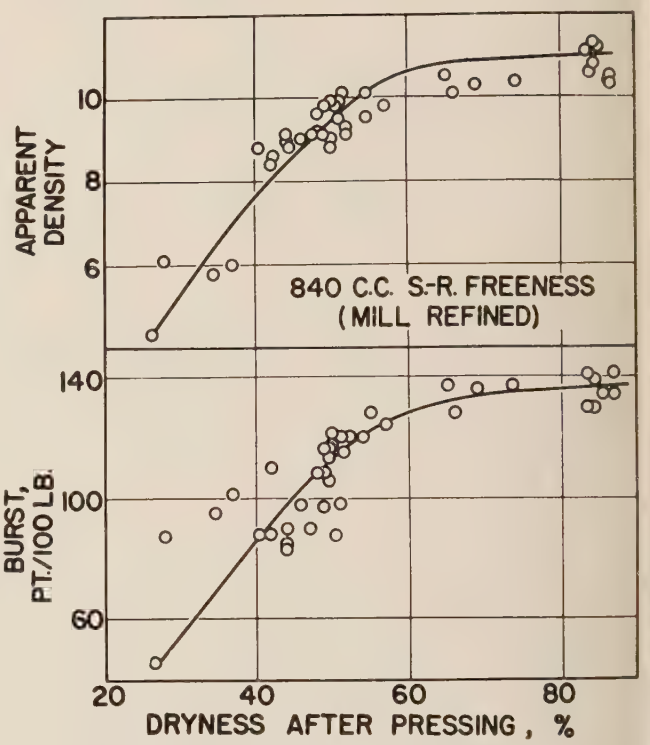

Fig. 9. Relationship between sheet dryness after pressing and sheet properties—mill-refined pulp

From these experiments and other parts of the larger program, it was concluded that for purposes of increasing the bursting strength through wet pressing, two or possibly three pressings at pressures not over about 300 to 400 lb. per line in., but otherwise as high as possible, would give maximum gain. Pressing to a moisture content of about 50% appeared to be optimum.

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The Evaluation of Paper Machine Stock Systems by Basis Weight Analysis

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Machine direction and profile measurements of basis weight show that the pattern of variations is not stable and is a characteristic of the particular paper machine. A number of different experimental and analytical techniques have been used to study basis weight variations as a means of evaluating paper machine stock systems. The variation of a single basis weight reading from the average value throughout the reel is considered as the sum of three components: one due to the positon of the sample across the machine, one to its position along the reel, and a residual random component. A cutting and weighing method of basis weight evaluation is compared with the use of a beta-ray gage, and the techniques of computing the standard deviations of the three components of variation are discussed. Examples are given of the way these components vary between a number of different high speed newsprint machines and with changing machine speed on a given machine. General conclusions are drawn and the factors which influence each of the three components are discussed. A method of recording the slice opening across the machine during actual operation is described, and the relationship between the slice profile and the stable basis weight profile for one machine reported. A study of the variations of the average basis weight with time is reported, and the method of separating cyclic and random components described. A short discussion is given of the insight the results give into routine basis weight control methods and also the way in which the methods are of use in considering the improvements to quality which are likely to result from changes in machine operation and design.

The measure of the performance of a paper machine must be in terms of the quantity and quality of paper it produces, in practice on the speed and efficiency at which it produces acceptable paper. The degree of uniformity of the paper as manufactured is probably the most important single criterion of performance because increasing uniformity favorably influences nearly every factor which tends to increase production and improve paper quality. It is thus a major consideration in the commercial business of making and selling paper.

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The finished paper is influenced by every stage of the papermaking process—by the raw materials, the pulping process, and by each section of the paper machine from fan pump and screens to the calender and reel. This aspect of papermaking emphasizes two important factors in paper machine operational research. First, that the paper itself is a valuable record of the operation of the machine and, second, that, in studying the finished paper, the major problem is one of isolating the influence of the various sections. The practical difficulties of first extracting and assembling the data and then of their analysis with the lengthy associated computations have proved a deterrent in the past to a detailed study from this approach.

This paper describes a series of experiments in which the basis weight variations of the finished sheet have been studied as a means of evaluating the stock system of a number of newsprint machines. Emphasis will be placed not on the particular results themselves, but on the value of the methods used as tools of paper machine operational research.

Previous investigators of wet end operation, including the authors' company, have used the addition of tracers to the stock at various points ahead of the position at which the sheet is formed on the wire and then determined their distribution in the finished paper. Some workers have used colored fibers and visual counting to study fiber orientation (*7*) and lateral diffusion on the wire (*15*), others have used fibers tagged by radioactive iodine and electronic counters for ease of automatic counting, with the additional possibility of making photographic prints for visual study (*11*, *14*). Such work is complementary to the present study.

BASIS WEIGHT DETERMINATION AND BETA-RAY GAGES

Until recently basis weight studies have involved the cutting, conditioning, and weighing of large numbers of samples. In much of our early work this method was used. The successful application of beta-ray substance gages to papermaking (*1*, *2*, *4*, *5*, *6*, *12*, *13*, *16*, *18*) has now provided a more speedy means of obtaining the basic data. Their great advantage is that

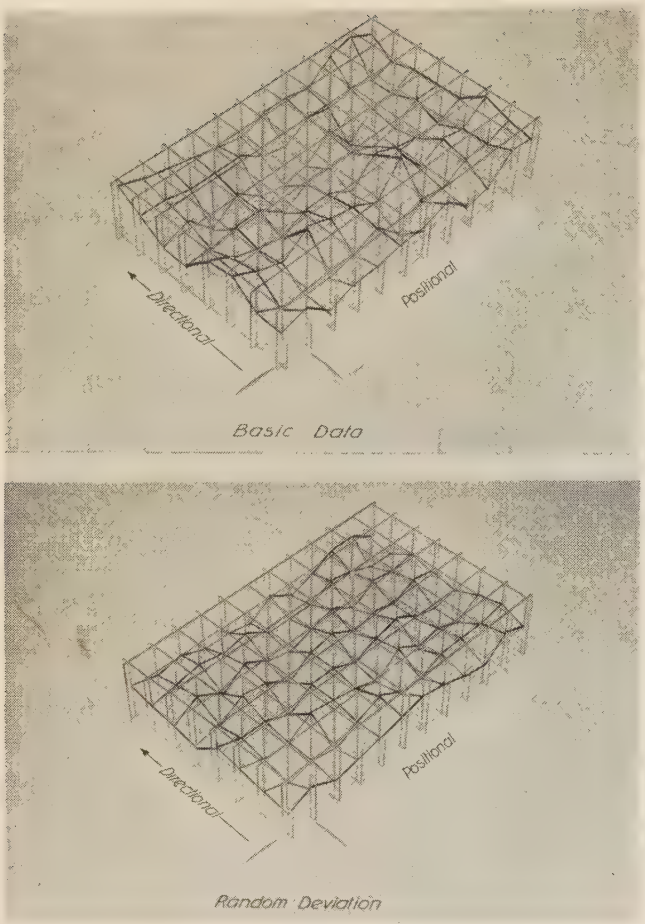

Fig. 1

testing becomes nondestructive and continuous. In most cases the major limitation to their extensive use as research tools is the lack of adequate computational aids to obtain the maximum information from the data.

The first application of the beta-ray gage was directed toward basis weight control, the signal from a gage metering the sheet at a fixed position across the sheet being used as a guide to manual adjustment or, more recently, for the automatic control of the stock gage (*6*, *16*, *18*). This work has repeatedly demonstrated the existence of variations of substance in the machine direction and the inadequacy of a single spot determination at the end of a reel for close control. The variations found have ranged from rapidly occurring ones equivalent to fractions of a second of operating time to slow drifts occurring throughout the reel.

Measurement of variations across the machine has been attempted either by a number of individual gage heads across the machine (*2*) or by traversing a single head (*12*). This latter method is not too satisfactory on wide machines because of the critical effect of variations in the gap between the source and the measuring head. A more satisfactory application has been the development of a separate gage, the profiler, through which strips taken across the machine can be scanned at slow speed away from the machine (*13*). Successive strips have shown that some of the variations are stable, while others vary from strip to strip.

Interest in these variations has been largely in the way in which they affect control on the machine. Large variations of a randomly occurring nature lead to wide control limits on a Shewhart chart and a consequent loss in precision of control. In addition they make spot determinations of basis weight of little value in following the process, often leading to too frequent adjustment of the machine.

THE GRAPHICAL REPRESENTATION OF BASIC WEIGHT VARIATIONS

The representation of basis weight variations occurring in a web of paper is analogous to that of representing the topography of a region, the weight at a point being equivalent to the elevation. In practice the basis weight data are usually obtained in the form of a succession of traverses across the web and are not sufficiently detailed to allow a contour map to be drawn. Discontinuous data can be presented three-dimensionally by graphing the traverses and mounting them vertically, in order, in a slotted base. A two-dimensional representation has been obtained by drawing circles proportionate in size to the weight, centered at a point corresponding to the sample position (*15*). When the data are obtained in the form of a continuous traverse, as from a betameter recorder, the profiles are already drawn and can be mounted directly to give a three-dimensional picture (*13*). The circle method is not very satisfactory for two-dimensional representation of continuous traverses. The authors have found that a more convenient way is to trace the traverses one below the other in order, displacing the origin of successive curves by a constant amount. This gives approximately the effect of looking down on the three-dimensional model along the machine direction.

To illustrate the ideas of the methods of analysis used in this paper two models have been made to represent some artificially constructed basis weight data. A set of eight equally spaced traverses, each with 1

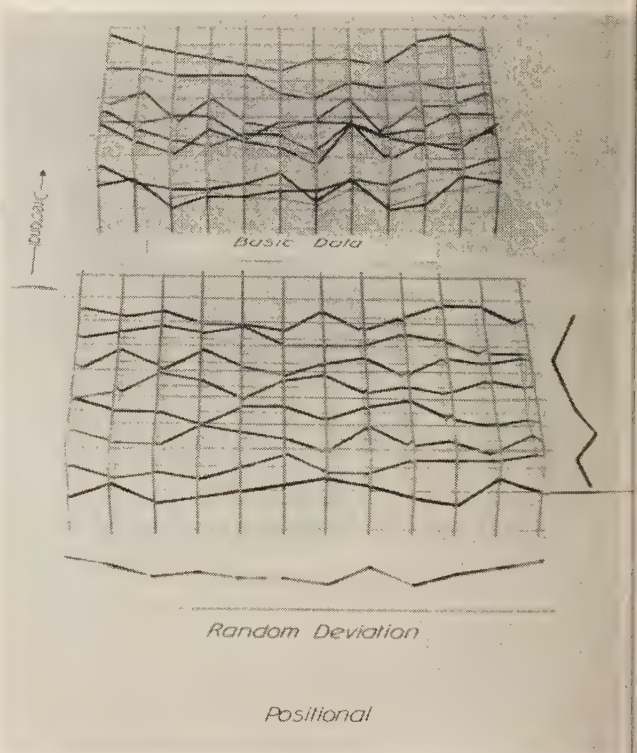

Fig. 2

equally spaced readings was devised, and these data were plotted on lucite strips to form the model labeled "basic data" in Figs. 1 and 2. The origin is taken as the average value of the product so that the readings are all deviations from this value. The scale is arbitrary. A two-dimensional representation of these data is shown in Fig. 3a in which the same effect as looking at the model from the viewpoint of Fig. 2 is achieved. The average profile across the machine and the average value of each traverse in the machine direction were calculated and are shown in Figs. 2 and 3b. The sum of the average value of the machine direction average and the positional average at every point of the model represents the stable pattern of variation shown in the model as a narrow line and in Fig. 3c. The difference between the stable pattern and the basic data is the random deviation plot, and a model of this is shown in Figs. 1, 2, and 3d. In practice it is not convenient to calculate the random deviation plot every time and instead a plot of the deviations from the mean profile is used, Fig. 3b. This is the combination of the random deviations and the machine directional ones and the relationship to the random plot is seen by comparing Figs. 3b and 3d.

In this paper basis weight data will be represented by plots of the type of Figs. 3a and 3b. Figures 4 to 7 and 9 to 17 are of this type, the only difference being that, in these cases, the basic data are sets of continuous traverses and are traced from the curvilinear coordinates of the beta-ray gage recorder charts.

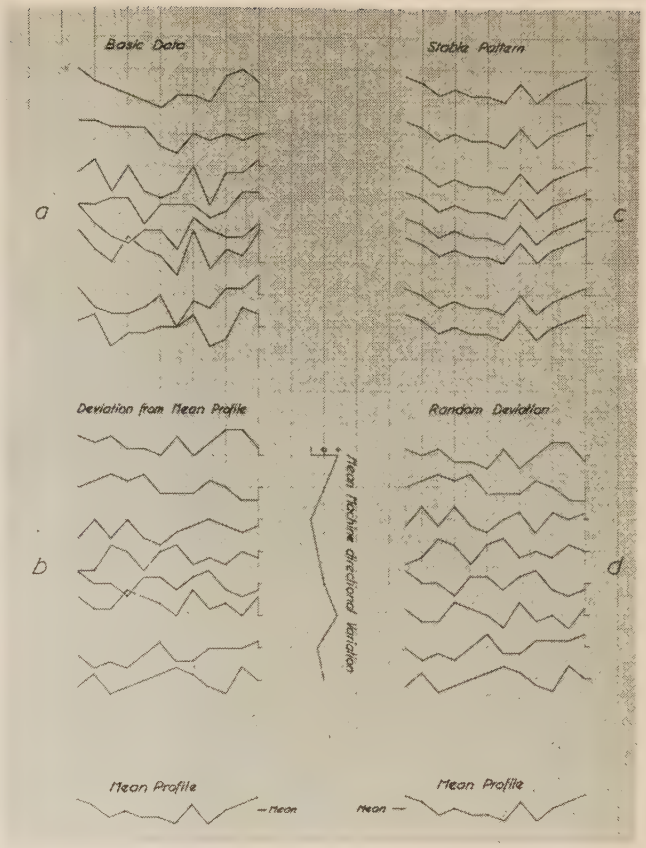

Fig. 3. Components of basis weight variation. Graphical analysis

THE MATHEMATICAL REPRESENTATION OF BASIS WEIGHT

As discussed above, variations in basis weight may be classified in three kinds: cross directional, machine directional, and randomly variable. Cross-directional variations are those which persist in successive profiles, machine directional are the variations in the average level across the sheet with time and random variations account for the residual variation. Since most methods of determining basis weight are subject to experimental error the residual variation is compounded of actual random variations in the paper and experimental error. These components are related as follows:

$$X_{ps} = \bar{X} + x_{p\cdot} + x_{\cdot s} + x_{ps} + \epsilon_{ps}$$

X_{ps} is the measured value of basis weight at the pth position across the machine and on the sth strip in the machine direction
$\bar{X}$ is the mean basis weight of the paper sampled
$x_{p\cdot}$ is the deviation of the average reading at the pth position from $\bar{X}$
$x_{\cdot s}$ is the deviation of the average reading of the sth strip from $\bar{X}$
x_{ps} is the random variation at the pth position of the sth strip
ϵ_{ps} is the experimental error in the value at the ps position

In practice it is not easy to separate x_{ps} and ϵ_{ps} and, provided the same experimental technique is used throughout an investigation, it is convenient to use their combined effect in a single random term. This treatment is logical since it is always necessary to use some means to determine the basis weight. The combining of these two factors, however, must not be disregarded in discussions of the minimum practical limit of random variations achievable on a machine when the experimental error sets a minimum value to the random terms as found by measurement.

For convenience we will write:

$$x_{ps} + \epsilon_{ps} = e_{ps}$$

so that

$$X_{ps} = \bar{X} + x_{p\cdot} + x_{\cdot s} + e_{ps}$$

The quantities $x_{p\cdot}$, $x_{\cdot s}$, x_{ps}, and e_{ps} are called the components of the basis weight variation and by definition their respective mean values are all zero. The components are uniquely defined for a given test by the basis weight figures themselves and their evaluation is a straightforward computational process (see Appendix A).

The actual components evaluated relate only to that particular test, but it is assumed that they form unbiased samples, characteristic of the paper. They are of interest in themselves as when the form of the random pattern is being studied or when the cause of a persistent deviation in the stable profile is being traced. In other studies the standard deviations or the frequency distrtibuions of the components are of more value. It is customary, then, to use the estimates of the standard deviations of the universe from which each sample is drawn and their derivation from the observed data is given in Appendix A.

The use of the components or their standard deviations as parameters by which wet end design and performance may be studied will become obvious when their properties have been established. Initially certain assumptions were made about these properties and these have been justified in the light of the accumulated experience.

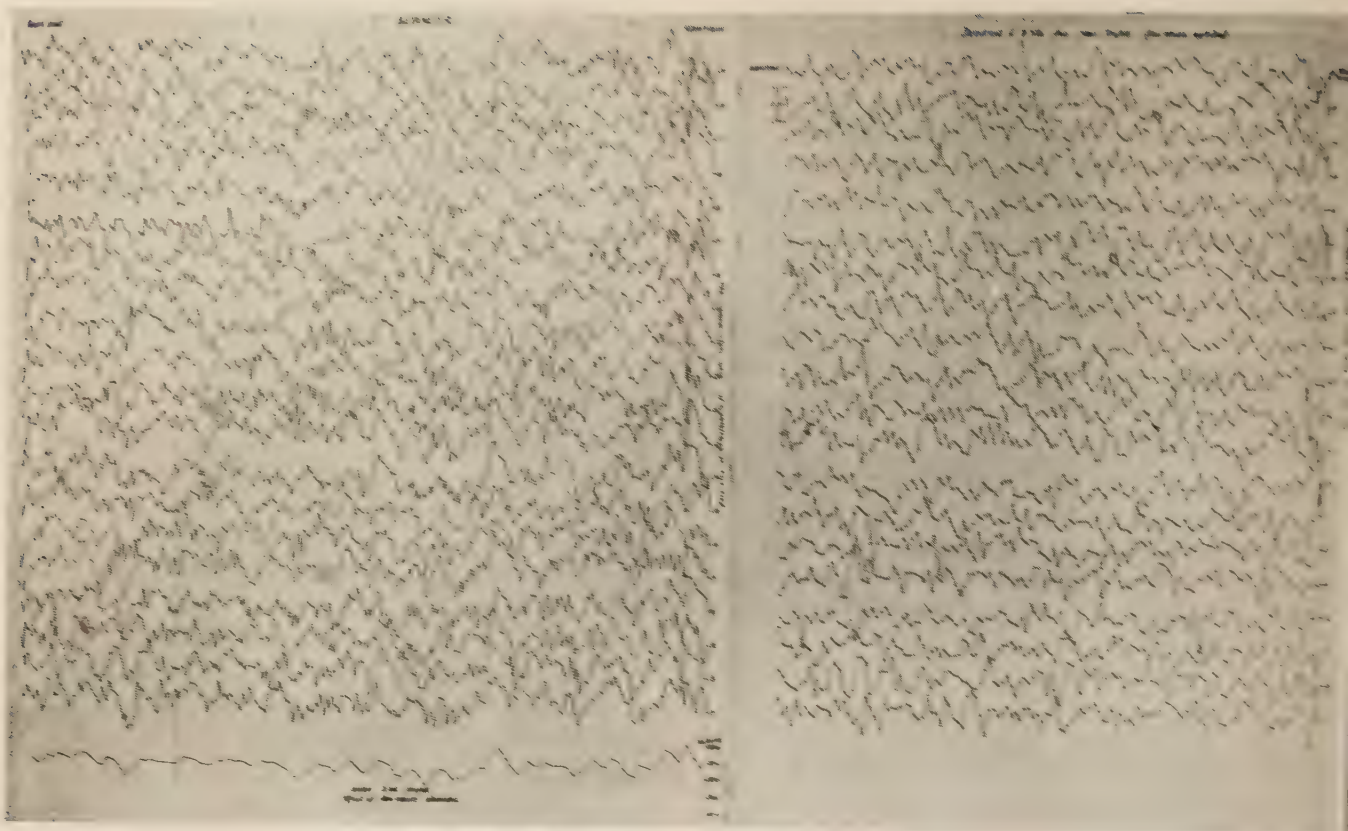

Fig. 4. Machine A (BW 11): speed 1770 f.p.m.

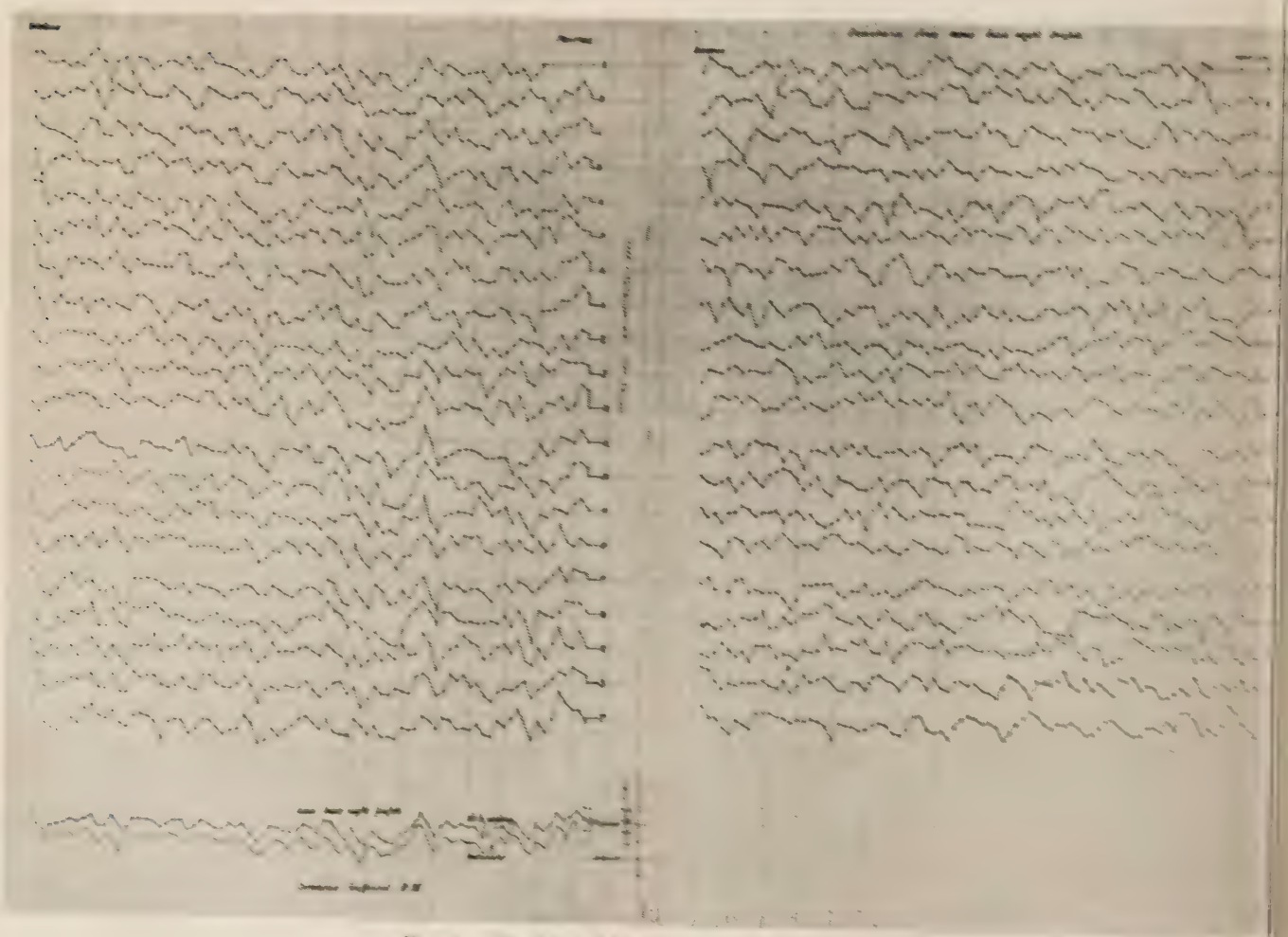

Fig. 5. Machine A (BW 9): speed 1770 f.p.m.

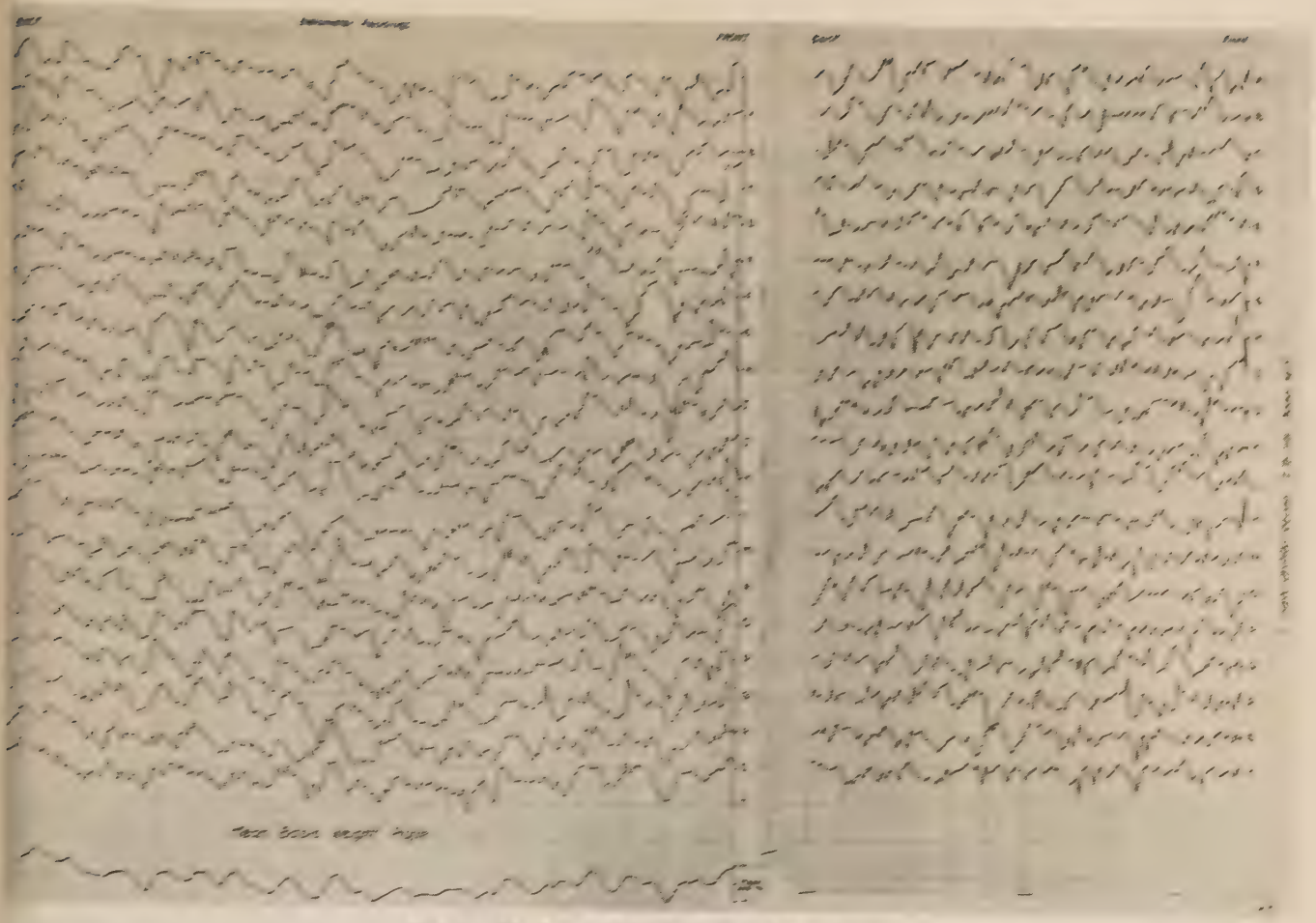

Fig. 6. Machine 3 (BM 3) speed 1745 f.p.m.

Fig. 7. Machine 4 (BM 24) speed 1915 f.p.m.

These assumptions are as follows:

1. That the components are orthogonal and are unbiased samples from a normally distributed universe. This assumption allows standard variance component analysis techniques and significance tests to be used.

2. That the components evaluated in a test are, within the usual statistical limits, characteristic of the machine performance under the conditions prevailing at the time of sampling. That is, a repetition of the test on the same occasion or on a similar occasion at a later date would have yielded the same results.

3. That the components are not in any way dependent on the means by which they are determined; that is to say, they are independent of the particular testing methods used to obtain the basic data. The components may, of course, be affected by the sampling methods and by the sampling size because these are inherent characteristics of any procedure for determining uniformity.

TESTING PROCEDURE AND A COMPARISON OF WEIGHING AND BETAMETER METHODS OF BASIS WEIGHT EVALUATION

Initially basis weight studies were made by cutting samples 8 by 2 in. at 3-in. centers across the machin and weighing the sample after conditioning. Examina tion of successive cross-directional strips taken at th reel showed a varying profile from strip to strip an in order to discover a pattern in the random com ponents of variation, the number of strips examine was gradually increased. Sampling and computin time increases directly as the number of samples and i was eventually necessary to balance the gain in infor mation and in the precision of estimation of the machin direction component with the increased labor involved The authors decided on 20 strips and prefer to adop another method when a more precise knowledge of th machine direction component is required. The resolu tion of the profile and of the random components ob tained is adequate for most purposes.

The standard procedure now adopted is to take 20-ply strip across the face of a full reel and wid enough for the test. The strips are therefore space with centers at a distance apart equal to the circum ference of the reel, usually about 11 ft. Each ply i profiled taking care that the starting points of the pro files are coincident. The present technique is to use beta-ray gage scanning a 14-in. wide strip at the rate o

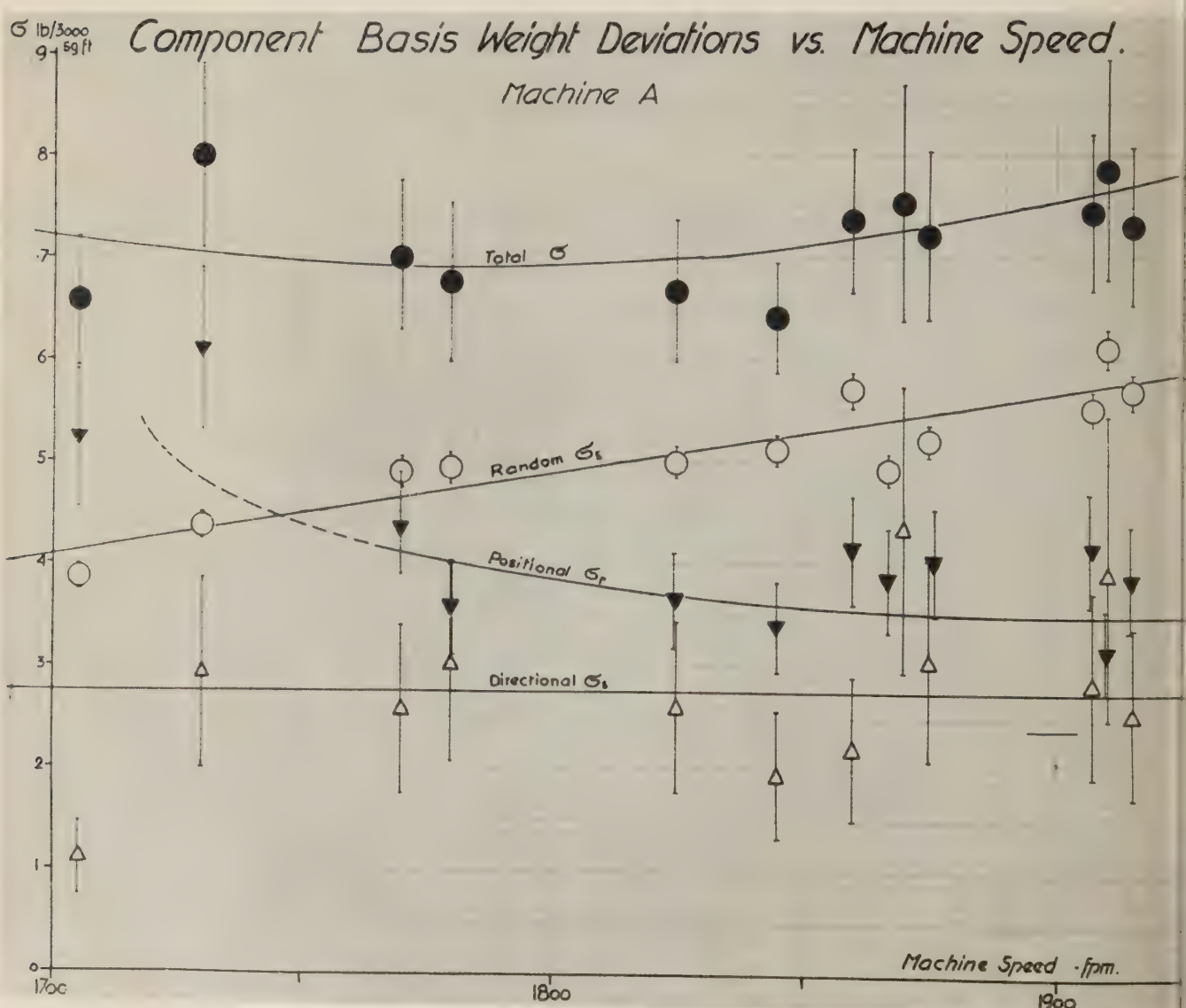

Fig. 8. Component basis weight deviations versus machine speed (machine A)

3 f.p.m. with short response time. The reading is thus the moving average of an area approximately 14 by 2 in., the latter being the gage width in the cross direction, plus the gage random emission. An estimate of the latter effect is obtained from a stationary sample placed in the gage.

Readings at equally spaced intervals along the profile are recorded and from them the average profile is calculated and graphed. A standard spacing equal to 2-in. centers at the slice has been chosen for betameter records. This corresponds to the flowevener spacing on our machines and to a noticed periodicity in their profiles. Other machines, at lower speeds, have not always shown the same marked coincidence of flowevener spacing and basis weight profile periodicity and so there has been no reason to vary the spacing from one machine to another. These machines have sometimes shown a definite periodicity not associated with floweveners and this has been attributed to effects such as drainage curtains and of carryback under the wire (influencing stock on the wire).

The deviation curve of the basis weight from the mean basis weight profile is calculated by subtracting the mean curve from each individual curve in turn. The deviation curves are then plotted one below the other as described for Fig. 3 above.

One of the early test strips was divided along its length and one side tested by the cutting and weighing method, BW9, and the other by the betameter, BW11. These results are shown graphically in Figs. 5 and 4, respectively; the variance components are given in Table I. It will be seen that the estimates of the residual and the machine direction variances are the same for the two methods, but that the weighing method gives a higher cross-directional variance which results in a correspondingly higher over-all variance. The correlation coefficient of the average cross-direction profiles by the two methods is 0.95, which is very high. Examination of the two profiles which have been graphed together at the bottom of Fig. 5 shows that such discrepancies as exist are caused by slight relative displacements of corresponding peaks or troughs which could easily be an experimental error in the traversing mechanism. The difference in values of the cross-direction components is due to a difference in sensitivity of the two methods to this component. The fact that the machine direction and random components are equivalent implies that the different sensitivity is not caused by inaccurate calibration of the beta-ray gage.

The equivalence of machine direction and random components obtained by the two methods has been

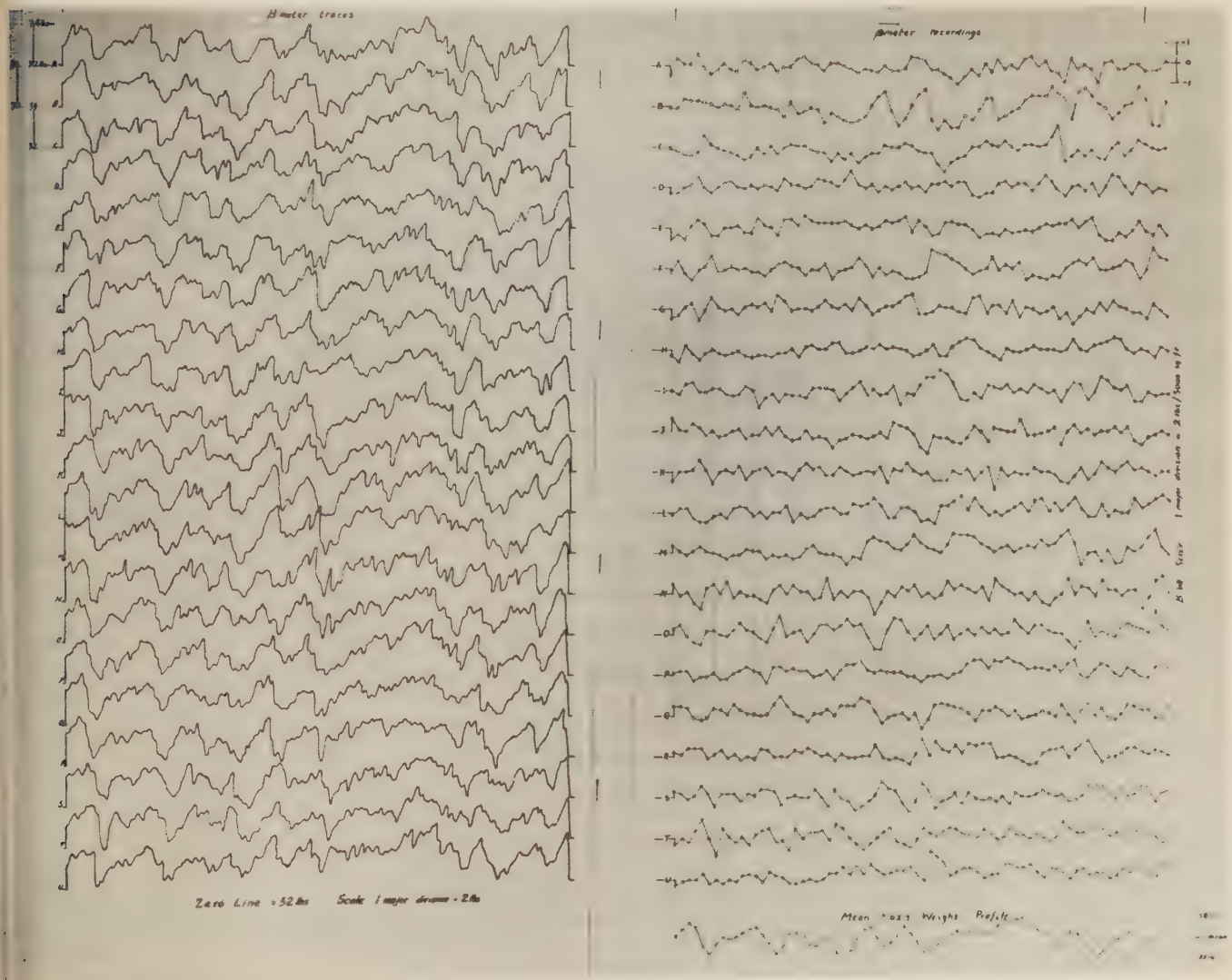

Fig. 9. Machine C (BW12): speed 1230 f.p.m.

Table I

Machine	Speed f.p.m.	Test no.	Standard deviations of basis weight variations, lb./3000 sq. ft. Total	Mach. dir.	Cross dir.	Residual
A	1705	BW18	0.657	0.111	0.522	0.386
			(0.063)	(0.036)	(0.068)	(0.012)
	1730	28	0.800	0.292	0.610	0.436
			(0.091)	(0.093)	(0.079)	(0.013)
	1770	11	0.699	0.257	0.434	0.489
			(0.076)	(0.082)	(0.055)	(0.015)
	1780	17	0.675	0.302	0.356	0.493
			(0.078)	(0.096)	(0.046)	(0.015)
	1825	19	0.667	0.260	0.364	0.499
			(0.069)	(0.083)	(0.047)	(0.015)
	1845	20	0.641	0.194	0.338	0.511
			(0.054)	(0.062)	(0.044)	(0.015)
	1860	23	0.737	0.220	0.414	0.571
			(0.071)	(0.070)	(0.053)	(0.017)
	1870	27	0.753	0.434	0.384	0.492
			(0.115)	(0.139)	(0.050)	(0.015)
	1875	26	0.722	0.306	0.402	0.521
			(0.082)	(0.098)	(0.052)	(0.016)
	1910	16	0.785	0.392	0.316	0.611
			(0.107)	(0.153)	(0.041)	(0.019)
	1910	25	0.744	0.284	0.415	0.552
			(0.077)	(0.090)	(0.054)	(0.017)
	1915	24	0.730	0.256	0.386	0.569
			(0.076)	(0.082)	(0.050)	(0.017)
	1770	9[a]	0.826	0.258	0.617	0.494
C	1230	12	0.552	0.120	0.436	0.320
D	1280	13	0.662	0.108	0.481	0.443
E	1300	15	0.738	0.456	0.461	0.370
F	1310	14	0.974	0.398	0.601	0.664
G	1600	21	0.698	0.296	0.564	0.296
H	1614	31	0.652	0.224	0.544	0.280
I	1614	30	0.720	0.328	0.467	0.447
J	1655	22	0.762	0.169	0.421	0.615
K	1660	10	0.847	0.171	0.581	0.595

[a] By the strip curing and weighing method. All the other tests were by beta-ray gage. This test was taken on adjacent samples to those of test no. 11.

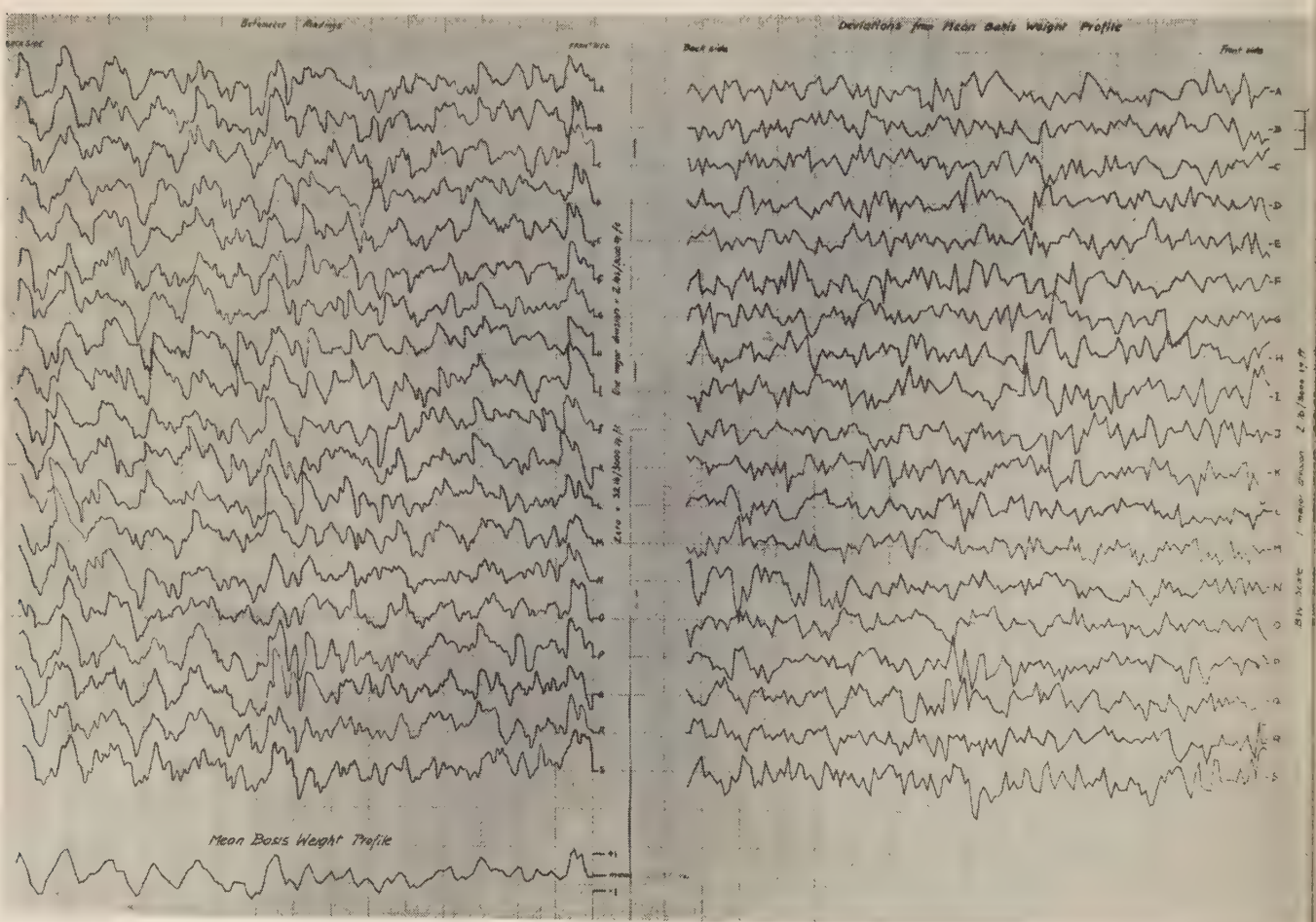

Fig. 10. Machine D (BW13): speed 1280 f.p.m.

confirmed on another machine, and the same ratio obtained between the values of the cross-direction components. The two profiles also showed the same high degree of correlation as above. The different sensitivities of the two methods, therefore, arises from the different methods of sampling in the two cases. This aspect has not been followed further as the interest is in comparative levels of component deviation on one machine and as between machines and also, because the testing procedure has been standardized with the beta-ray gage.

This technique of component analysis has been used for two types of study. First, it has been used to investigate the basis weight variation components on no. 2 machine of Quebec North Shore Paper Co. at Baie Comeau, designated as machine A in this paper, under normal operating conditions and throughout its speed range to see whether an estimate could be made of the probable values of these components at higher operating speeds. Second, it has been used to provide a method of rationalizing the performance of the major types of high-speed newsprint machines as a complementary study to an investigation into headbox design.

BASIS WEIGHT VERSUS SPEED TRENDS

The result of a series of 12 tests on machine A operated in the speed range 1705 to 1915 f.p.m. are summarized in Table I. The figures in brackets are the 95% confidence limits for each of the components. The beta-ray curves, the deviation curves, and the average profile of three of these tests are shown in Figs. 4, 6, and 7. The relationship of the components with the machine speed is shown in Fig. 8 together with speed trend lines.

Knowledge of the total deviation alone is of little use for prediction purposes as these readings establish no obvious trend. The components of variation, however, give some insight into the behavior of the basis weight variations with changing operating speed.

The standard deviation of the cross-direction profile or positional component decreases from a maximum at 1700 f.p.m. to a value of 0.350 lb. around 1880 f.p.m. That of the machine direction or directional component,

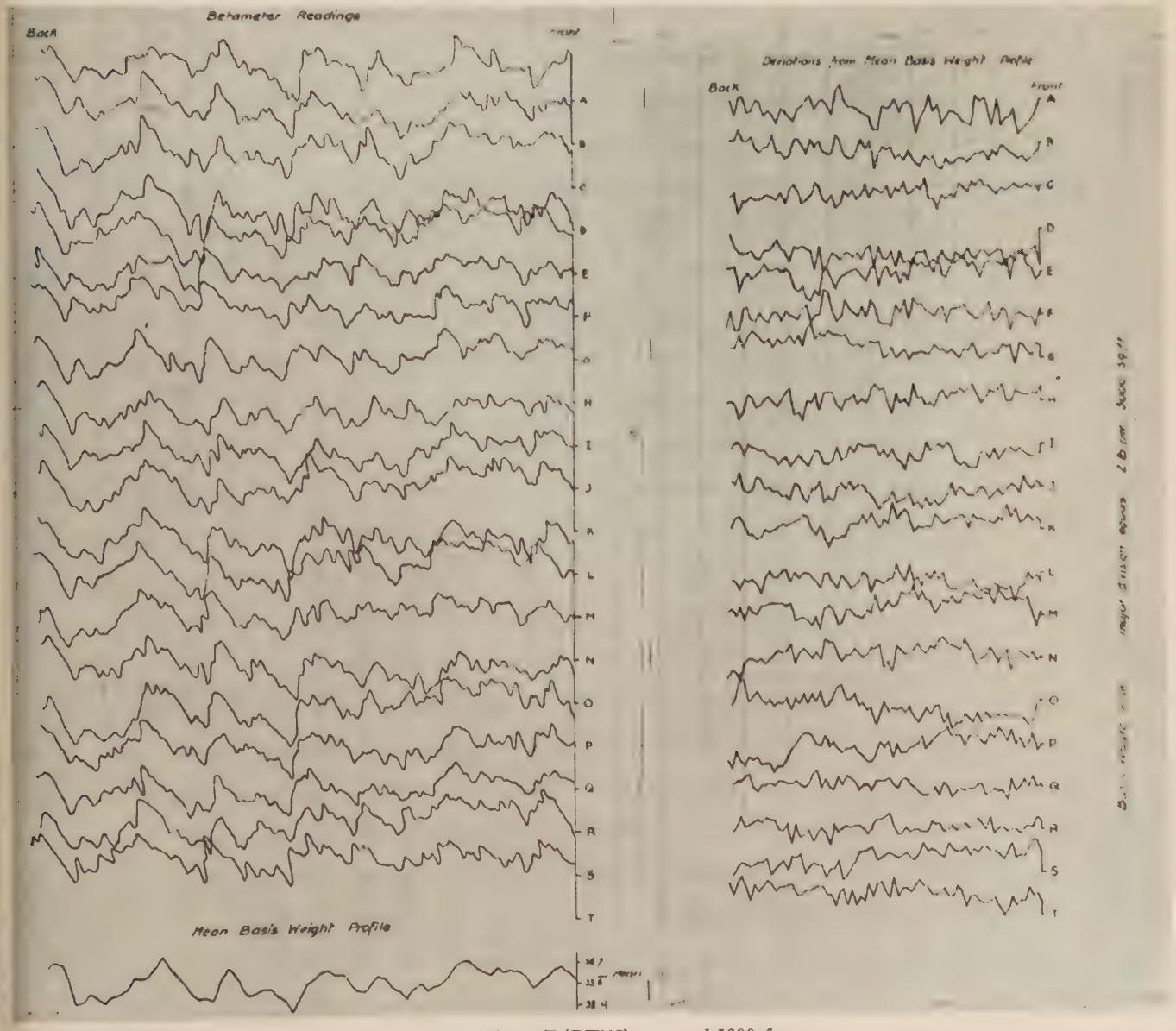

Fig. 11. Machine E (BW15): speed 1300 f.p.m.

the least closely defined, shows no significant trend in the speed range and is distributed about 0.275 lb. The random variation shows a definite upward trend throughout the range from approximately 0.4 to 0.6 lb. The total basis weight trend is computed from the individual trends using equation (A4) of Appendix A.

The samples tested were taken under normal operating conditions, thus to obtain a sample at a given speed an occasion on which the machine was running at that speed was chosen. On any particular occasion for production requirements the machine speed is as high as is compatible with an acceptable running efficiency. This is determined to a large extent by the frequency of breaks, a high percentage of which occur at the wet end. Since wet web strength is a function of basis weight as well as of specific strength, a wide range of basis weight variation increases the possibility of a break. At a given speed the machine direction and random components are largely predetermined for the particular machine, so that the only operational adjustment affecting the basis weight variations is the slice adjustment acting through its effect on the profile. Normal operation of machine A is to start up at the beginning of the week around 1700 f.p.m. and increase the speed as the machine is brought into adjustment. Thus, the increase of speed corresponds to a leveling of the sheet. The value of 0.350 lb. appears to be the optimum profile variation with the present equipment and criteria of machine control on machine A and so once this value is reached, the total variation begins to increase. The practical speed limit is reached when the increasing variations of basis weight adversely affect efficiency and this usually occurs at the level of 0.8 lb. per 3000 sq. ft.

A COMPARISON OF DIFFERENT HIGH-SPEED NEWS MACHINES

Although nominally a standardized product, newsprint is produced over a wide range of speeds (500 to 1915 f.p.m.) and on machines of widely divergent design. The greatest diversity of design occurs in stock inlets and headboxes and it is to be expected therefore that this diversity should be reflected in the paper they produce.

Ten machines have been selected as typifying the range of designs in use and samples from them were tested by the method of analysis of variance components as described above. They fall into three speed

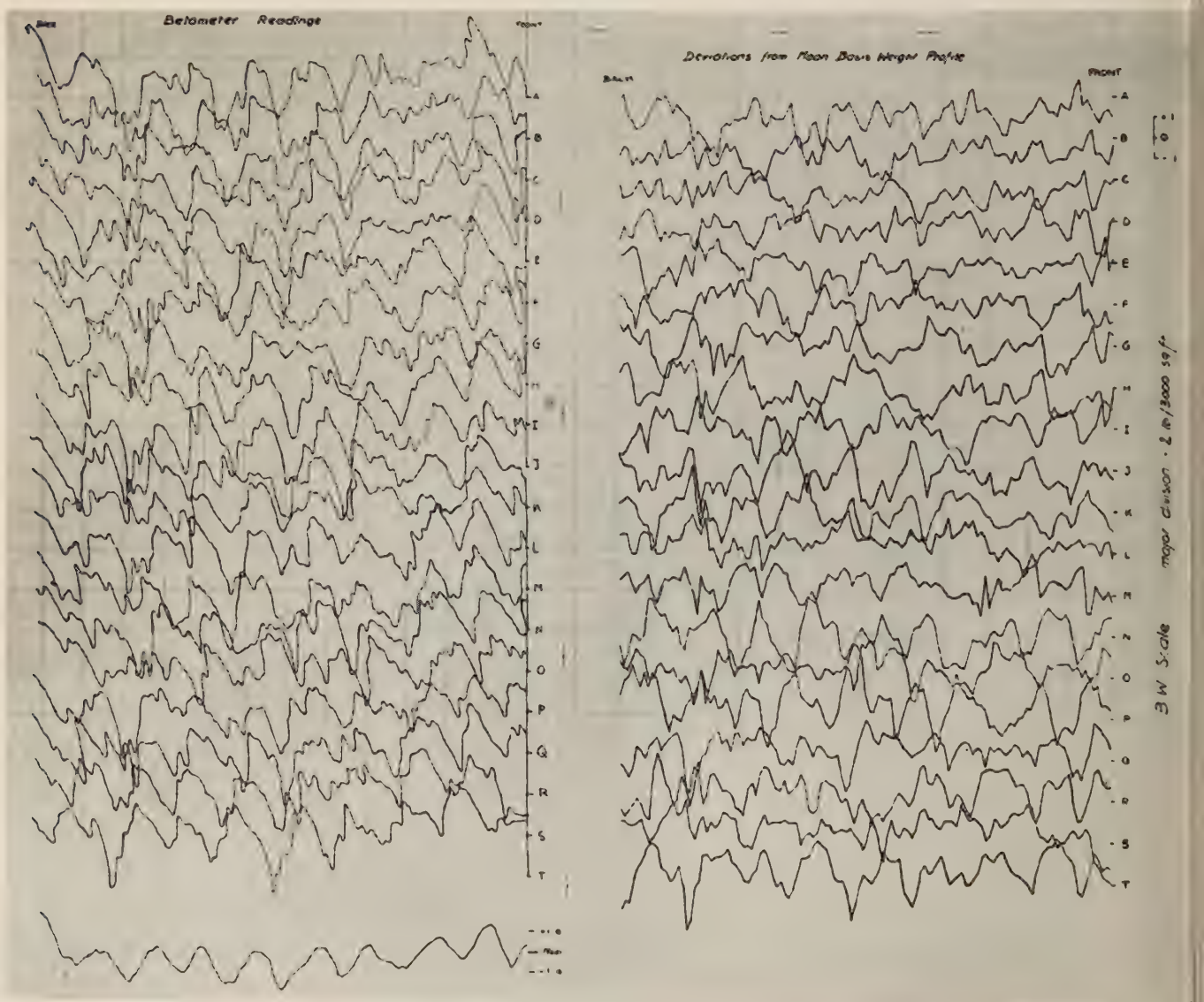

Fig. 12. Machine F (BW14): speed 1310 f.p.m.

groupings. The beta-ray profiles, the deviation curves, and the stable profile for each are shown in Figs. 9 to 17 and the components of variation summarized in Table I.

While there is a general tendency for the total variation to increase with speed the difference between machines within a speed group is often as large as that between ones in different groups. It is therefore interesting to speculate on the particular aspects of design which contribute to these differences. To do this it is necessary to consider the kind of factors which can influence each component.

The most obvious thing affecting the stable profile and therefore the cross-direction component is the slice setting. An experiment will be described in the next section showing such a relationship for machine A. It becomes evident, however, that other things also contribute. Such things as fixed internal fittings in the headbox, flow vanes, and guides may cause a non-uniformity of velocity or of consistency in their wake which will produce a permanent streak. Usually these streaks are too narrow to be eliminated by a slice adjustment. It is also possible that some of this variation is caused on the table, but such effects must be small for no significant difference has been found on machine A between samples made normally and on a slack wire. In addition, in the diffusion experiments of Mason *et al.* (*11*) on two high-speed newsprint machines it was found that the relative movement on the table, in the cross direction, of tagged fibers added at the slice has a mean value less than 0.9-in. Channelling of flow in the headbox can also contribute to a stable non-uniform profile and, in general, it is not easy to compensate for this effect by slice adjustment. Factors affecting profile are characterized as being constant with respect to time and variable with respect to position.

Machine direction variations are those occurring

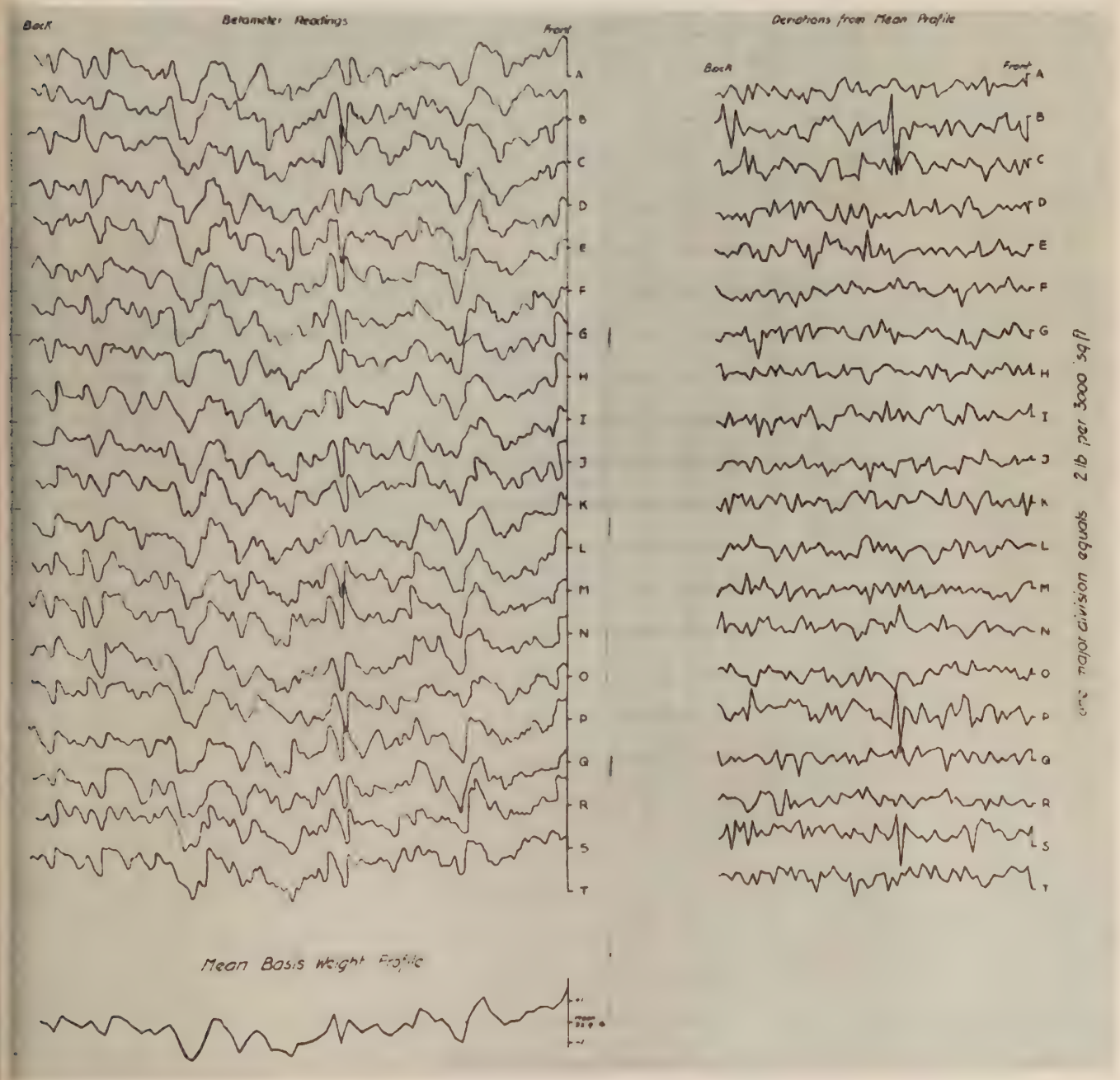

Fig. 13. Machine G (BW21): Speed 1600 f.p.m.

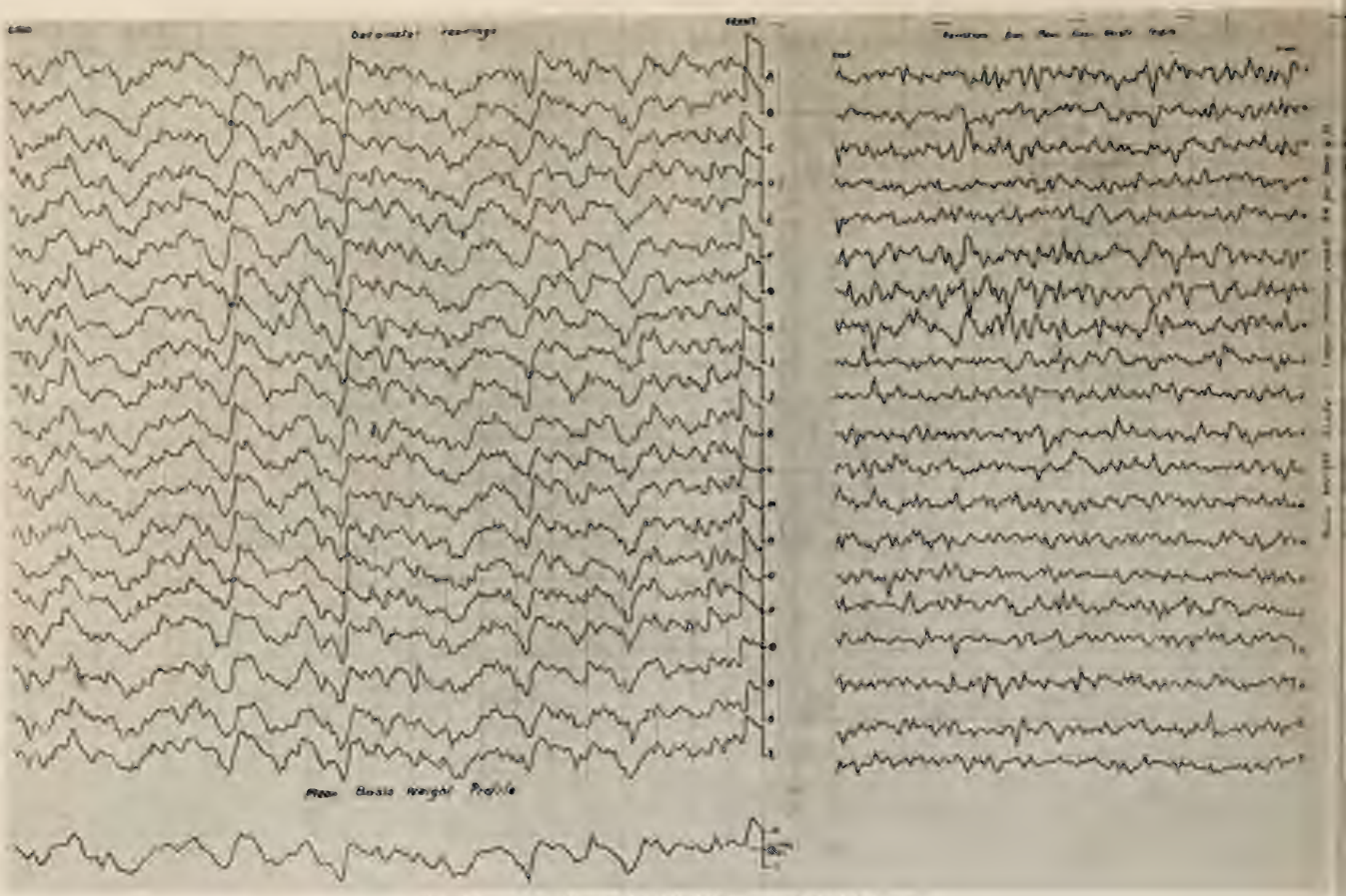

Fig. 14. Machine II (BW 31): speed 1614 f.p.m.

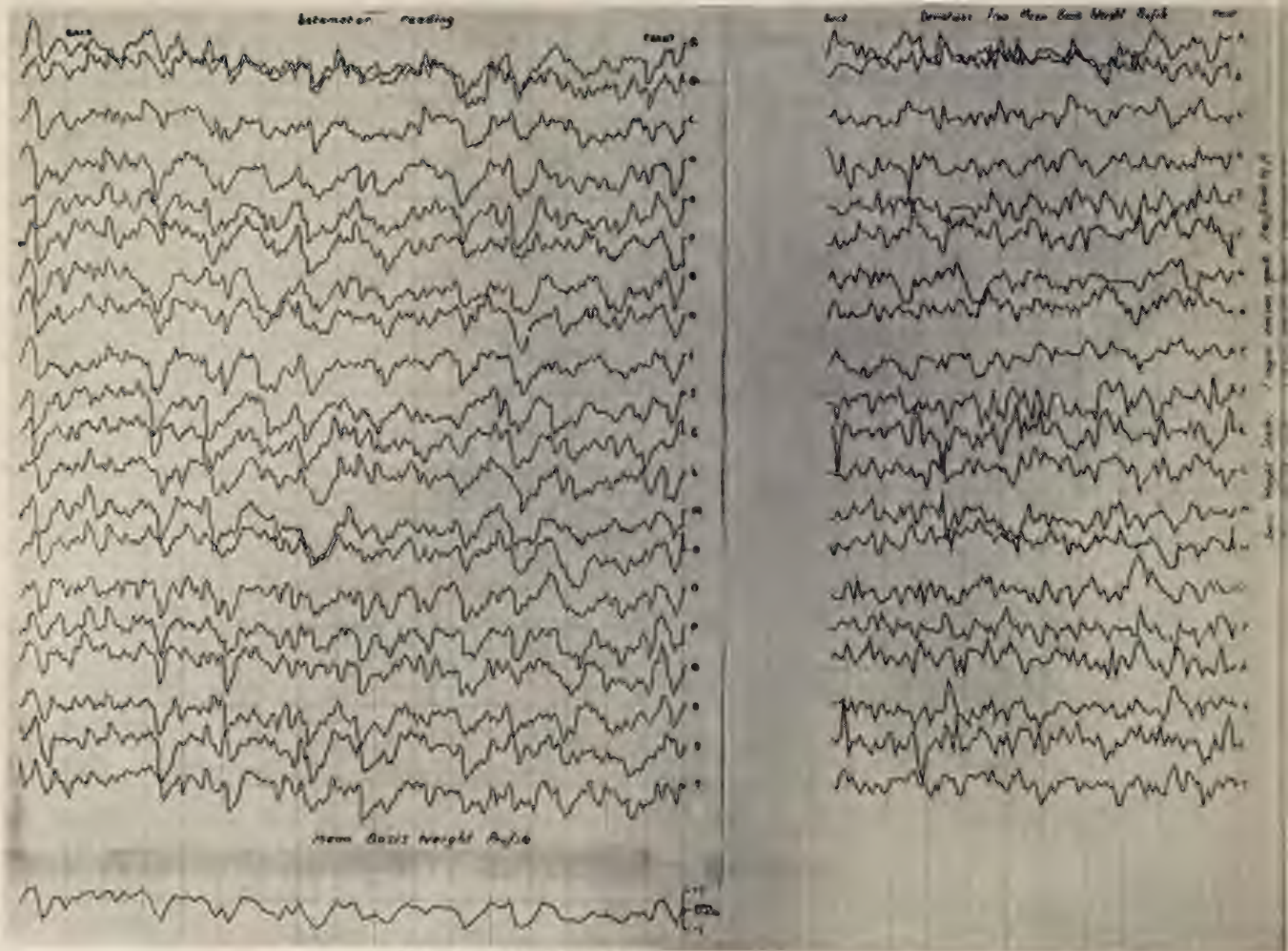

Fig. 15. Machine I (BW30): speed 1614 f.p.m.

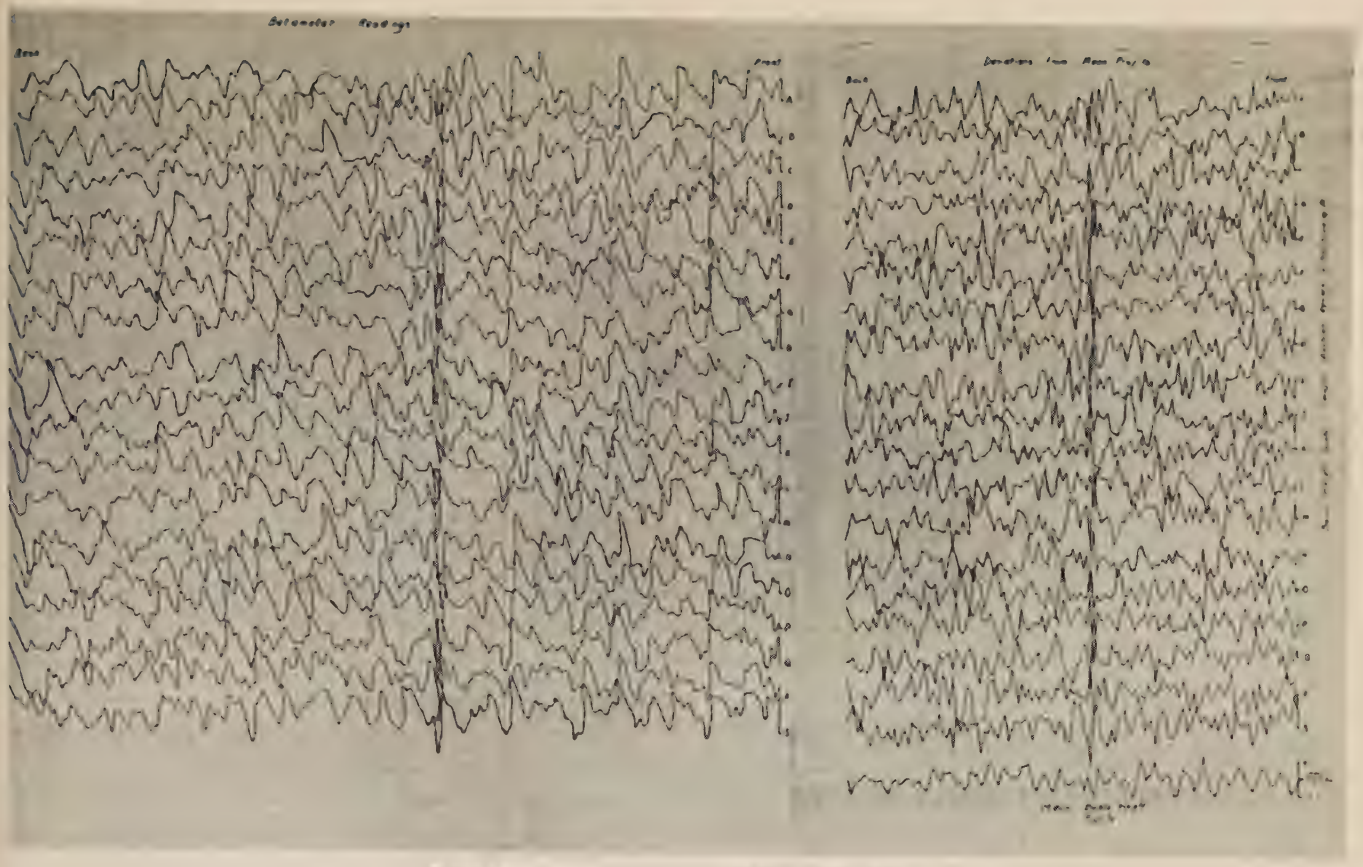

Fig. 16. Machine J (BW22): speed 1655 f.p.m.

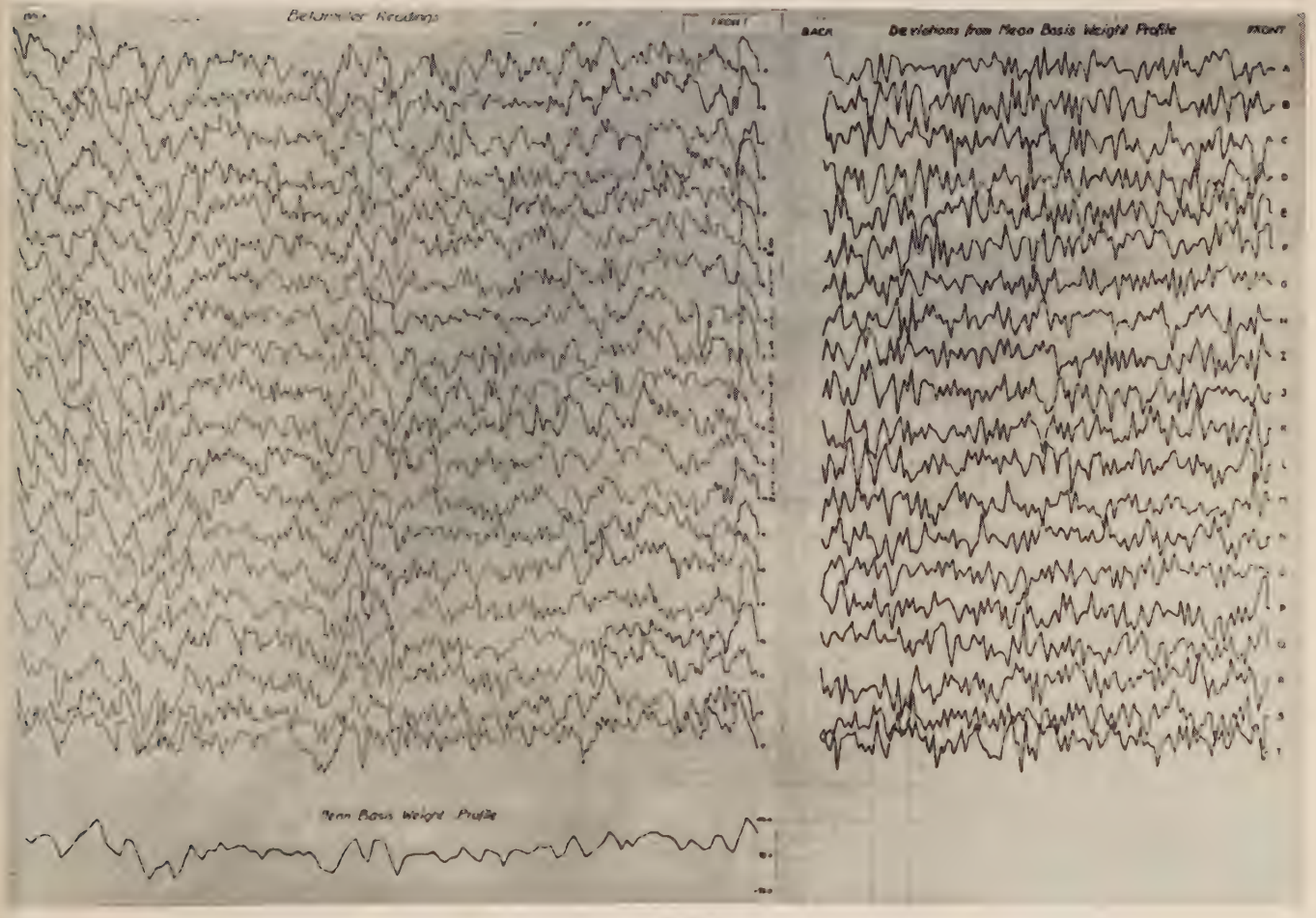

Fig. 17. Machine K (BW21): speed 1660 f.p.m.

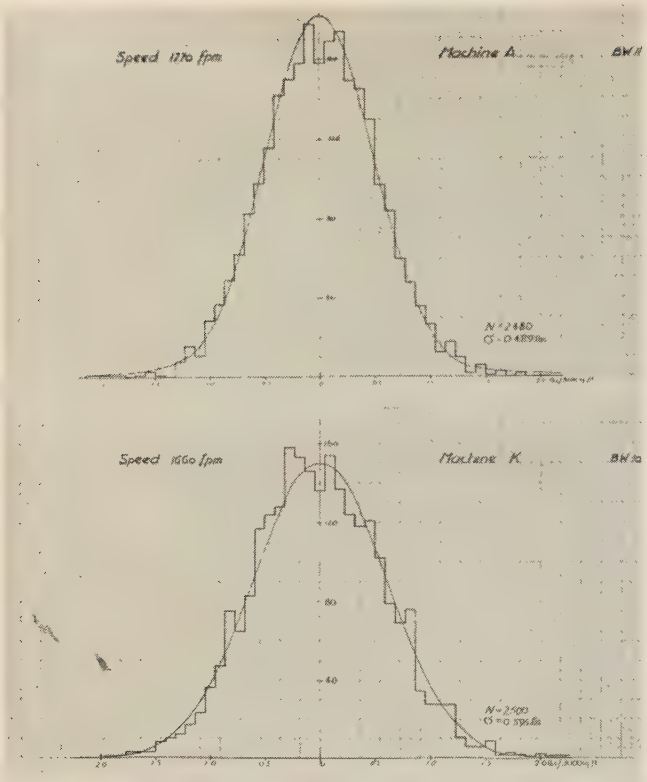

Fig. 18. Distribution of random component of basis weight variation

in the average value across the machine with time. Thus, they are characterized as being dependent on time and independent of position across the machine. Variations may be either periodic, when they are caused as a result of rotating elements, in the headbox or table for example, or by periodic oscillations in the system, or else aperiodic, caused by drifts and random fluctuations in such factors as consistency or rate of flow of stock. Sergeant (*15*) mentioned an example where a periodic variation was traced to a faulty roll in the headbox. Since most machines now run as partially or completely closed systems there is a strong possibility for oscillation in the system to be set up in a similar manner to electrical and acoustic feedback oscillations. A study of this aspect of machine directional variation requires more elaborate techniques than the component analysis described above and will be dealt with later.

Random variations are characterized by being neither constant in time nor position. They are caused by local fluctuations in the flow of stock and of its consistency in the system and on the machine. Such variations of velocity are usually referred to in papermaking parlance by the word "turbulence," a description which is not always equivalent to the strictly hydrodynamic use of the word. It is convenient to classify fluctuations in velocity either as small scale or as large scale turbulence although, in practice, the scale of turbulence is continuous. Small scale turbulence affects the dispersion of the stock and therefore the formation of the paper, whereas larger scale turbulence produces a nonuniformity of basis weight. The position is compromised when turbulence in the headbox is used to insure mixing. The random component of basis weight is a measure of the large scale turbulence in a headbox.

The intensity and scale of turbulence desirable in newsprint manufacture and the design of a headbox to produce this are outside the scope of this paper. Indeed, there would seem to be a wide divergence of opinion on this matter in the industry (*10*). It is safe to conclude, however, that a sheet with a high random component of basis weight variation will be difficult to run on the machine and that the variability of substance will cause a corresponding variability in finish.

In the previous section it was found that, for machine A, there exists a definite increase in the random component as the speed increases. Although no other machine was studied in as complete detail, there are indications that such an increase is not inevitable. Machines C, G, and H have headboxes of the same basic design as one another, but proportioned for their respective speeds. Examination of their components shows that, even if it proves impossible to design a headbox which has components independent of speed, it is possible to proportion the design to give the same components at a higher speed. On the other hand, machines D and J, though of the same basic design as one another, show an increase in random variation with the higher speed. This may be taken as evidence that the way random variation varies with operating speed is a matter of machine design.

The variance component deviations do not by themselves give a complete story and reference to the beta-ray traces shows additional characteristics of the machines. Machine A, for instance, shows a fairly regular bunching of profiles and consequently a strong probability of cyclic variations in the machine direction. This feature was followed up and is described below. Machine K, on the other hand, shows a pattern the authors have called "rocking." Thus, a bunching of curves on the front side occurs midway between the bunching on the back side. Patterns similar to machine A, which the authors have called "jumping," occur on some of the other machines, machine I for example, while machine E combines both types of patterns. Others, such as machine F, suggest what papermakers call "snaking."

Features such as these can be put in terms of statistical attributes, for example, the "rocking" effect leads to a platykurtic (broad humped) distribution of the random component, while a "jumping" effect will give a high machine directional component, which will also

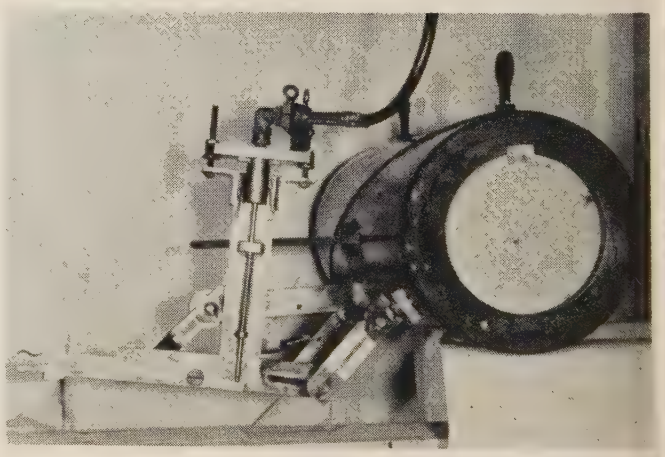

Fig. 19

show a marked periodicity, and have a normal distribution of random components. The distribution of random components for machines A and K are shown in Fig. 18.

Practically, however, it is more profitable to note these effects and then turn the investigation to the machine itself to find a cause.

THE CORRELATION OF SLICE PROFILE AND BASIS WEIGHT PROFILE

An association of the slice opening profile with the stable or average basis weight profile is to be expected and the extent of the correlation is of interest. An experiment was carried out on machine A to determine the value for that particular machine.

The papermakers of this machine reported that, during the first few hours after start-up, the character of the slice changed, gradually reaching an equilibrium state. This led us to suspect an actual change in slice profile over the first few hours and so it became necessary to devise a means for measuring the slice during operation. A scissors gage was designed to traverse the slice on a carriage and is shown in Fig. 19. The opening was measured electronically by making a linkage attached to the scissors one plate of a condenser in a capacitance bridge and, after suitable amplification, recording the signal as the carriage traversed the machine. The traverse was carried out immediately before a machine shutdown. Prior to this test samples were taken from the six preceding reels and the average basis weight profiles determined by the cutting and weighing method. After the machine was stopped, a traverse was repeated and also a series of micrometer readings taken at regular intervals. This information is recorded in Fig. 20. The strip weights are recorded as grams per 80 sq. in.

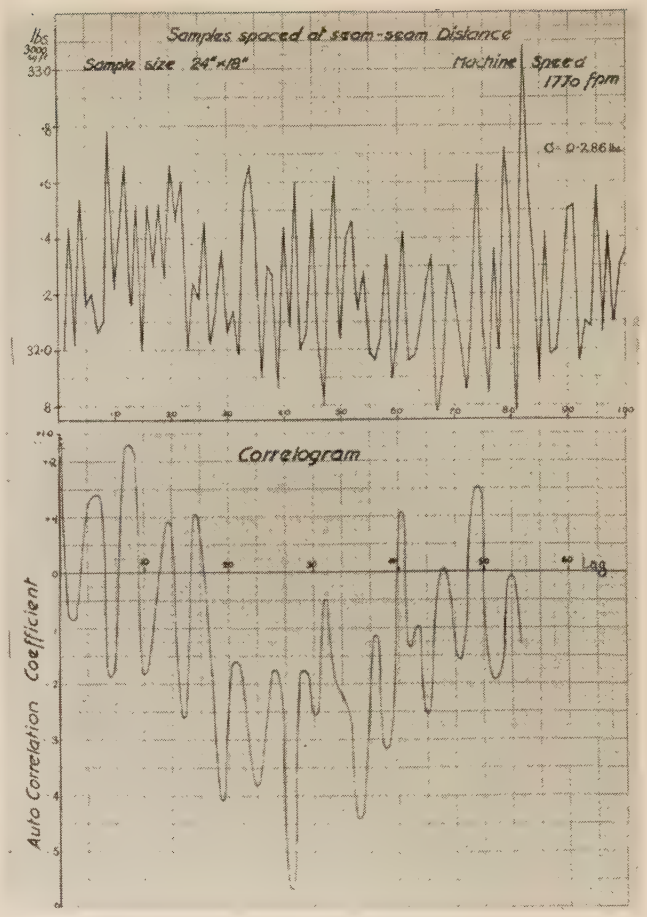

Fig. 21. Machine directional basis weight variation

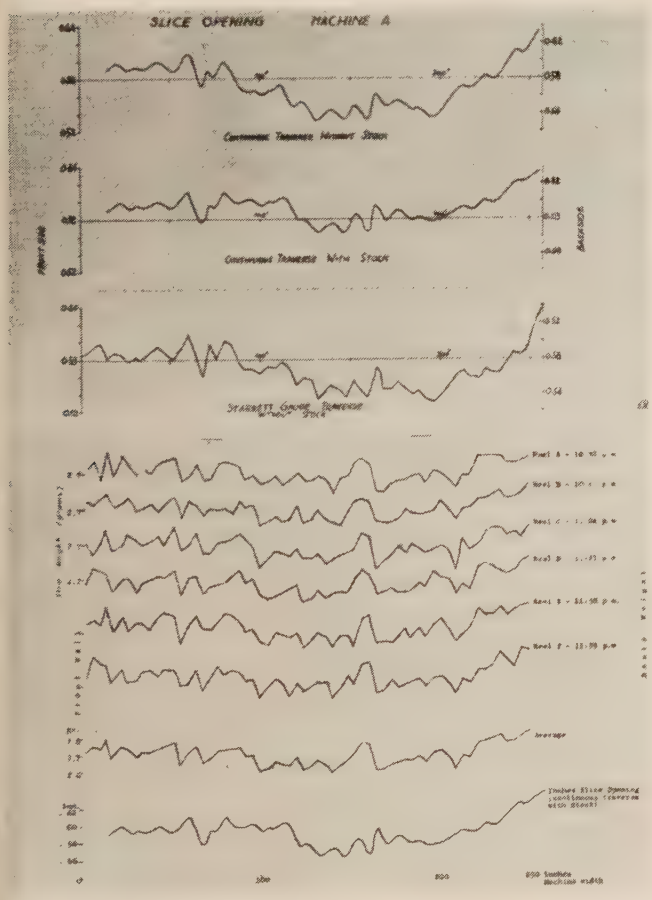

Fig. 20

From the traverses it was established that the change of slice profile is a fact, and a good check on the gage and recording equipment was obtained. The correlation coefficient of slice opening and of basis weight profile, the latter adjusted for lateral shrinkage, was 0.465, a figure highly significant at the 0.1% probability level. Other factors also influence the average profile and it is probable that they are interacting with the slice profile to produce some of the slight displacement of details and distortion of shape between the two profiles.

THE ANALYSIS OF MACHINE DIRECTIONAL VARIATIONS FOR PERIODICITY

Sergeant has described (*15*) how, in a case of a very pronounced periodicity of basis weight in the machine direction, it was traced to a faulty roll in the headbox and how the variations were subsequently reduced on replacing the offending roll. When a study can be completed by this line of approach a more detailed one is unnecessary. A machine's behavior is not, unfortunately, always so easily diagnosed and corrected. If periodic variations are not very pronounced, or if several different periodicities are compounded, their isolation requires an analytical technique. The theory for such a technique exists, but the authors are still in the process of exploiting its application to paper machine evaluation. Its usefulness will become evident only if

the information it gives may be applied to improving the machine design or operation.

A series of samples 24 by 18-in. were taken on machine A at regular intervals. The original interval chosen was that of the wire seam mark spacing on the paper, in order to eliminate possible table effects. The results are shown at the top of Fig. 21. They show a fairly large variability and evidence of periodicity. From these data was computed the correlogram, that is, the auto-correlation of samples in the series at progressively increasing separation (see Appendix B). This calculation is equivalent to making the phases of the periodic variations identical at the origin and, since it also concentrates the random effects at the origin, the resulting curve is a smoothed recombination of the periodicities in the data. The correlogram thus enables a rapid estimate to be made of the pronounced periods in the data.

This procedure is equivalent to the computation of the Patterson diagram which is used as a preliminary step in the structure determination of crystals by the Fourier analysis of their x-ray diffraction patterns.

The correlogram is shown at the bottom of Fig. 21. Two periods are clearly defined, at intervals of approximately 4 and 120 samples and others at approximately 8 and 33 may also be present. One interval represents 105 ft. $1^1/_2$-in. in the finished paper or approximately 3.5 sec. on the machine, giving time periods of 14 sec. and 7 min., with other ones suspected at 28 sec. and 2 min.

A subsequent test was done at shorter spaced intervals and this showed up a period of 7 sec., which, although present in the above data for short periods of the test (see readings 13–27), were not evident throughout and consequently not resolved in the correlogram.

The next stage in a detailed investigation, once the range of periodicities has been established, is a Fourier analysis of the data to obtain the periodogram. This diagram represents the amplitude of the terms in the Fourier expansion of the data and enables the total variation to be apportioned between the random variations and the observed periodic ones. In the authors' case this stage of the analysis has not yet been reached. The use of a beta-ray gage, although simplifying the measurement of the basis weight has shown up a far wider range of periods than was suspected from the early tests and the problem of economically analyzing the data with the tabulating equipment available is still being solved.

Two types of periodicity are possible: one is caused by assymmetry in a revolving part of the machine such as an unsymmetrically drilled perforated roll in the headbox, and the other by periodic fluctuation about a steady state in some part of the stock system which can either occur at such positions as the point of mixing of stock and white water or else be associated with the average retention time of the white water systems. It should prove possible to distinguish the two types by the breadth of the peaks in the periodogram. The mechanically created periodicities will be narrow, those due to flow instability broad and less sharply defined.

CONCLUSIONS

The idea of using the finished paper as a tool for evaluating the performance of a paper machine and thus eventually as an aid to the design of either improvements in operation and equipment or of a new paper machine has been developed. The methods used involve analytical techniques which, although not widely known in the industry, have been successfully applied elsewhere. For this reason, emphasis has been placed both on the idea and the kinds of methods available, rather than on the results so far obtained. The interpretation of the results of such an analysis requires an appreciation of the analytical methods themselves and also of the fundamentals of paper machine operation. Although the papermaking process is a continuous one, it is a succession of separate operations and a critical examination of these operations does allow a classification and differentiation of their respective effects on the finished paper.

The usefulness of the idea has been demonstrated by the two applications described, one to a detailed analysis of a particular machine over its normal operating range and the other of a comparison of a number of different newsprint machines operating at three different speed levels. By means of the analysis it is possible to apportion the variability in the product between the various sections of the machine and thereby focus attention on those factors which, if improved, would have the most beneficial effect on the paper. Furthermore, since the relative effect of these factors has been shown to vary widely between different machines, it also provides a basis for a program of development work.

A third application for studying the fundamentals of closed white water systems has been outlined. This application uses a technique which is still relatively new in statistical theory. Its usefulness will become apparent when more experience is gained in the interpretation of the results.

A practical outcome of these studies is the insight it gives into routine methods of basis weight testing and control on the machine. When it is realized that, superposed on the stable profile and average machine directional variations of substance, most high-speed machines have an appreciable random component it will be seen that testing methods which rely on sampling once per reel are liable to considerable error. A continuous measuring method, which can automatically average out the random effect, becomes of increasing value for weight control. In addition, the need for two types of instruments, one to continually meter at a fixed position across the machine and another to periodically test the average weight profile, has been well established. The development of two types of beta-ray gages along these lines represents a useful advance toward improved machine operation.

APPENDIX A

Analysis of Variance Components

In the section on "The Mathematical Representation of Basis Weight" the relationship between a particular basis weight reading, the average weight and the component of variation was given as

$$X_{ps} = \bar{\bar{X}} + x_{p.} + x_{.s} + x_{ps} + \epsilon_{ps} \qquad \text{(A1)}$$

and writing

$$x_{ps} + \epsilon_{ps} = e_{ps} \qquad \text{(A2)}$$

Table AI

Source of variation	*Degrees of freedom*	*Sums of squares*	*Mean squares*	*Expected mean squares*	*F*
Between positions	$m - 1$	$\sum_{p=1}^{m} (X_{p.} - \bar{X})^2$	$\frac{\sum_{p=1}^{m} (X_{p.} - \bar{X})^2}{m - 1} = S_1$	$\sigma_e^2 + n\sigma_p^2$	S_1/S_3
Between strips	$n - 1$	$\sum_{s=1}^{n} (X_{.s} - \bar{X})^2$	$\frac{\sum_{s=1}^{n} (X_{.s} - \bar{X})^2}{n - 1} = S_2$	$\sigma_e^2 + m\sigma_s^2$	S_2/S_3
Random	$(m - 1)(n - 1)$	$\sum_{p,s} (X_{ps} - X_{p.} - X_{.s} + \bar{X})^2$	$\sum_{p,s} \frac{(X_{ps} - X_{p.} - X_{.s} + \bar{X})^2}{(m - 1)(n - 1)} = S_3$	σ_e^2	...
Total	$mn - 1$	$\sum_{p,s} (X_{ps} - \bar{X})^2$	$\sum_{p,s} \frac{(X_{ps} - \bar{X})^2}{mn - 1} = S_4$	$\sigma_e^2 + \frac{n(m-1)\sigma_p^2 + m(n-1)\sigma_s^2}{mn - 1}$	...

equation (A1) becomes

$$X_{ps} = \bar{X} + x_{p.} + x_{.s} + e_{ps} \qquad \text{(A3)}$$

Define $N = n \times m$ where m, n are the number of positions across a strip and the number of strips, respectively.

σ = standard deviation of total variation of basis weight of the paper produced
σ_p = standard deviation of variation of positional means
σ_s = standard deviation of variation of strip means
σ_e = standard deviation of residual or random variation

These standard deviations are related by the equation

$$\sigma^2 = \sigma_p^2 + \sigma_s^2 + \sigma_e^2 \qquad \text{(A4)}$$

Define

$$X_{p.} = \frac{\sum_{s=1}^{n} X_{ps}}{n} \qquad \text{(A5)}$$

$$X_{.s} = \frac{\sum_{p=1}^{m} X_{ps}}{m} \qquad \text{(A6)}$$

and

$$\bar{X} = \frac{\sum_{p=1}^{m} \cdot \sum_{s=1}^{n} X_{ps}}{N} \qquad \text{(A7)}$$

The method of evaluating σ_p, σ_s, and σ_e from the observed data is termed variance component analysis. The underlying theory and choice of mathematical model has been discussed by Eisenhart (*8*) and Lee Crump (*9*). The statistics which are required in the calculation are tabulated in Table AI and the values of the σ's are found by equating the numerical "mean squares" with the "expected mean squares." The ratio of the mean squares is tested by "F" test and in all machines studied to date the test has been highly significant at 1% level.

The reliability of the estimates of the components of basis weight variance can be calculated, assuming a normal frequency distribution of the deviations. This estimate is still quite good if the distribution deviates from normality to some extent. The 95% confidence level has been chosen for this work and is computed for the three components as follows:

positional

$$\sigma_p \pm \sigma_p\sqrt{2/(m-1)}$$

machine directional

$$\sigma_s \pm \sigma_s\sqrt{2/(n-1)}$$

random

$$\sigma_e \pm \sigma_e\sqrt{2/(m-1)(n-1)}$$

total

$$\sigma \pm \frac{\sqrt{2}}{\sqrt{(m-1)(n-1)}}\left[\frac{\sigma_p^2(n-1) + \sigma_s^2(m-1) + \sigma_e^2}{\sqrt{\sigma_p^2 + \sigma_s^2 + \sigma_e^2}}\right]$$

These equations were used to calculate the limits shown in Table I and in Fig. 8.

APPENDIX B

Time Series Analysis

In studies of the machine directional component of basis weight variation it is customary to take readings at equally spaced intervals. Although not strictly necessary this simplifies the computations very much.

Define such a series of n equally spaced readings as

$$x_1, x_2, x_3, \ldots x_{r-1}, x_r, x_{r+1} \ldots x_n$$

The average value, μ, of this series is given by

$$\mu = \frac{\sum_{r=1}^{n} x_r}{n} \qquad \text{(B1)}$$

The serial covariance of lag s (written C_s) is the covariance of terms in the series taken s apart, thus

$$C_s = \frac{1}{n-s} \cdot \sum_{r=1}^{n-s} (x_r - \mu)(x_{r+s} - \mu) \qquad \text{(B2)}$$

approximating

$$\sum_{r=1}^{n-s} (x_r + x_{r+s}) \text{ to } 2(n-s)\mu$$

$$C_s \simeq \frac{1}{n-s} \cdot \left[\sum_{r=1}^{n-s} x_r \cdot x_{r+s} - (n-s)\mu^2\right]$$

$$\simeq \frac{1}{n-s} \cdot \sum_{r=1}^{n-s} x_r \cdot x_{r+s} - \mu^2 \qquad \text{(B3)}$$

This is the form usually used for computations.

$$n \cdot b \cdot C_0 = \text{the variance of } x_r$$

$$= \frac{1}{n} \cdot \sum_{r=1}^{n} (x_r - \mu)^2 \qquad \text{(B4)}$$

The auto-correlation of lag s (written R_s) is defined as

$$R_s = \frac{C_s}{C_0} \qquad \text{(B5)}$$

R_s is the value plotted at point s on the correlogram, also

$$R_0 \equiv 1 \qquad \text{(B6)}$$

The periodogram may be derived in two ways and both have been used in practice (*3*, *17*). The classical approach is a direct Fourier analysis of the basic data, thus the intensity corresponding to a frequency p (written I_p) is given by

$$I_p = A_p^2 + B_p^2 \qquad \text{(B7)}$$

where

$$A_p = \sqrt{\frac{2}{n}} \cdot \sum_{r=1}^{n} x_r \cdot \cos\left(\frac{rp}{n} \cdot 2\pi\right) \qquad \text{(B8)}$$

$$B_p = \sqrt{\frac{2}{n}} \cdot \sum_{r=1}^{n} x_r \cdot \sin\left(\frac{rp}{n} \cdot 2\pi\right) \qquad \text{(B9)}$$

The alternative approach is by means of the correlogram and because some averaging out of the random component is achieved the result is called a "smoothed periodogram." A smoothing ratio m is decided upon and then the series of n readings is divided into subgroups of $n' = n/m$ readings. The calculation is the equivalent to computing the periodogram for each subgroup and averaging the results. Thus

$$I_p = 2 \sum_{s=-n'+1}^{n'-1} C_s \left(1 - \frac{|s|}{n'}\right) \cdot \cos\left(\frac{sp}{n'} \cdot 2\pi\right) \qquad \text{(B10)}$$

but

$$C_s = C_{-s} \qquad \text{(B11)}$$

therefore

$$I_p = 2\left[C_0 + 2 \sum_{s=1}^{n'-1} C_s \cdot \left(1 - \frac{s}{n'}\right) \cos\left(\frac{sp}{n'} \cdot 2\pi\right)\right] \qquad \text{(B12)}$$

For a random series the expected value of I_p (written $E(I_p)$), is independent of p and given by

$$E(I_p) = 2\sigma^2 \qquad \text{(B13)}$$

so that it is customary in the periodogram to plot $I_p/2\sigma^2$ against p.

A random series, therefore, has a constant expected value of unity, and a value significantly higher than unity at a frequency p indicates a periodic component of that frequency and of intensity equal to the area under the peak.

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The Measurement of Paper Machine Draws and Speed Variation

D. L. SHINN

A device for the measurement of machine draws, and speed and draw variation is described. It consists of two wheel units, and oscilloscope, a control box with power transformer, switches, electric timer, and two electromechanical counters.

A VARIETY of devices are used in paper mills for measuring paper machine speeds, and the differences in speeds between the various sections. These differences are called draws. The simplest equipment is the knife blade or pencil, applied at the end of a roll shaft to facilitate counting revolutions per unit of time. At the other end of the scale are the differential electric tachometers, mounted permanently on the machine, indicating or recording speeds and draw values. The equipment to be used in a given case must be carefully chosen to provide the desired measurements.

The device to be described was designed with one particular project in mind, and has been found to be well suited to the requirements.

The problem involved was the measurement of machine draws, and speed and draw variation, in the majority of the Crown Zellerbach Corp. paper machines. This involved tests on 36 machines located in seven mills. For this purpose, measuring equipment was desired, meeting the following requirements: (1) a high degree of accuracy, combined with rugged construction; (2) portability; (3) least possible interference with machine crews and production; and (4) localized presentation of data, so that all readings and observations could be taken by one operator,

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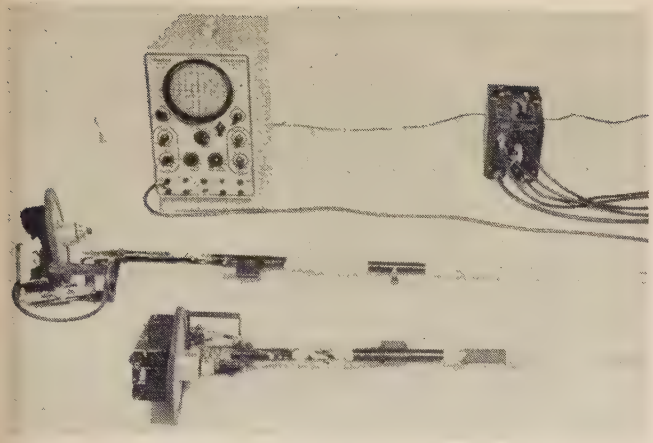

Fig. 1. Equipment for measuring paper-machine draws and speed variation

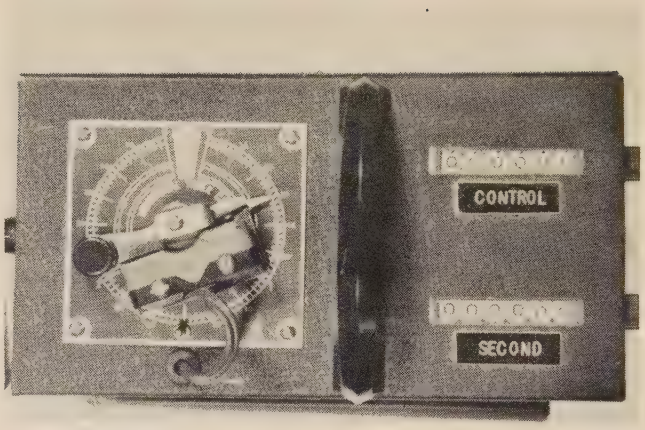

Fig. 3. Top view of control counter box

with helpers, unfamiliar with the equipment, to be recruited at the various mills.

The equipment constructed to meet these requirements is shown in Fig. 1. It consists of two wheel units, an oscilloscope, a control box with power transformer, switches, electric timer, and two electromechanical counters. Enough extension cord is included to allow the wheel units to operate at the extreme ends of the longest paper machine to be tested.

A closeup of one of the wheel units, with protective cover removed, is shown in Fig. 2. The wheel is 24 in. in circumference, including the thin rubber tire. The wheel shaft, turning on ball bearings, carries a cam serving to open and close a microswitch at each revolution, and an iron gear visible in the picture. The gear teeth pass close to the pole pieces of a magnet-solenoid unit, so that the solenoid produces an alternating current varying in frequency with the rate of rotation of the gear. Also visible is a toggle-switch which connects either the microswitch or the solenoid to an electric cord extending from the wheel unit to the control box, shown in Fig. 3. This is a view of the top of the control box. Each counter, shown to the right, indicates the number of revolutions made by one of the wheel units during the time interval set on the timer. The counter reading, multiplied by two, equals the travel in feet of the paper machine section being tested during that time interval. The counters thus simultaneously measure web speed at any two points in the machine, giving both speed and draw figures. Wiring diagram of the control box is shown in Fig. 4.

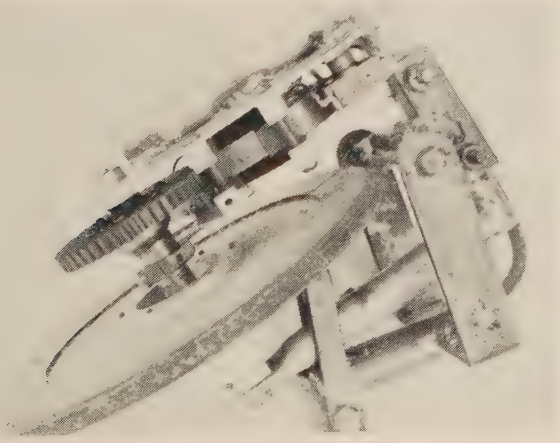

Fig. 2. Detail of wheel measuring unit

Figure 5 shows an operator holding one of the wheel units on a couch roll. Oscilloscope and control box are visible near operator's elbow.

In making the measurements as described above, two operators are required. Each holds one wheel unit in the machine at the point to be measured. The holder of the "control" wheel then presses a button, located on the handle, which starts the interval timer at the control box. The counters start, and at the same time small neon lights, mounted on the wheel units, flash on and off during the counting interval. By this means each operator knows when the count is completed.

The oscilloscope is used for determining variations in speed and draw. For this operation, the switches at the wheel units are positioned to connect the gear-wheel pickup units to the control box. Here the selector switch is turned to "scope" position, which combines the currents from the wheel units and connects them to the vertical deflection input terminals of the oscilloscope. The horizontal movement of the scope spot

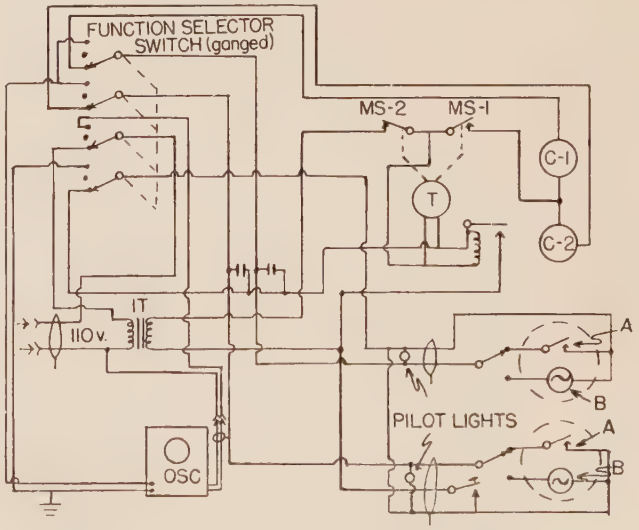

Fig. 4. Wiring diagram of draw apparatus

T—Timer. C1—Counter no. 1. C2—Counter no. 2. OSC—Oscilloscope. IT—Isolation transformer.

A—Make and break devices to activate counters with each revolution of speed wheel. B—Gear wheels pass through magnetic field to generate alternating current.

MS 1 & 2—Micro switches connected mechanically with timer T. MS 1 closing starts counting period; MS 2 opening stops counting period and resets timer.

Table I. Draw Measurements on Newsprint Machines

Machine designation	Wire speed, f.p.m.	Drawn, wire to 1st press f.p.m.	Drawn, wire to 1st press %	Draw, 1st press to 2nd, f.p.m.	Draw, 2nd press to driers, f.p.m.	Draw, between drier sections, f.p.m.	Draw, driers to reel, f.p.m.	Draw, wire to reel, %
A	1464	+92	6.3	+14	+19	...	−1	+8.5
A	1456	+94	6.5	+10	+10	...	+8	+8.4
B	1476	+84	5.7	+16	+14	...	+2	+7.8
C	1144	+56	4.9	+12	+ 2	+12	+2	+7.3
C	1144	+52	4.6	+14	+ 1	+ 7	+8	+7.2
D	1140	+60	5.3	+14	+ 2	− 2	+6	+7.0
E	1274	+72	5.6	− 6	+28	...	−8	+6.8
D	1156	+53	4.6	+14	+ 2	− 6	+10	+6.3
F	1435	+65	4.5	+ 3	+14	...	+8	+6.3
C	1156	+44	3.8	+14	+10	− 2	+2	+5.9
G[a]	1660	0	0.0	+20	+57	...	+5	+4.9
G[a]	1632	0	0.0	+ 8	+58	...	+8	+4.5

[a] Machine has vacuum pickup.

is controlled by the standard sawtooth generator in the oscilloscope, the frequency being adjustable by the panel controls of the oscilloscope. If now one of the wheels is caused to rotate, a wave form similar to a sine wave, will appear on the scope tube, and will in general appear to drift either to right or to left. Adjustment of the sweep frequency will stop the drift, the condition then is that the vertical frequency is an exact multiple of the horizontal sweep frequency. If now the rate of rotation of the wheel changes, the scope pattern will drift one way or the other; to the left for increase in speed, or to the right for a decrease. Since the wheel is 24 in. in circumference, and there are approximately 48 teeth on the pickup gear wheel,* it follows that each wavelength of drift represents one tooth on the gear wheel, or $^1/_2$ in. at the periphery of the wheel. Thus to determine amount of speed change, the scope observer counts wavelengths of drift per unit of time by use of a stopwatch. As an example, 4 wavelengths of drift per second are equivalent to 2 in. per sec., or 10 f.p.m. change in wheel speed.

* Actually one gear has 50 teeth and the other 45 teeth, to insure an interference pattern when measuring a very small draw with the two wheel units, as will be described.

In testing a draw with the oscilloscope, both wheel units may be used simultaneously. An interference pattern results from the combination of two sine waves of different frequencies. In this case the two signals alternately reinforce and oppose each other, the composite pattern showing a series of wide and narrow areas. As in the use of one wheel alone, the drift speed of these areas can be timed and draw variation calculated as in the example given above. Care must be exercised in interpretation of results in the use of two wheels, however, since an over-all machine speed change will produce a drift in the scope pattern as well as a draw change. The method has value, however, where machine speed characteristics have been observed by using the single wheel technique, and these have been taken into account in interpreting the data obtained with the two wheels. Three men are required for these measurements: one to hold each of the wheel units and the third to adjust and observe the oscilloscope.

The equipment operated very satisfactorily on the survey of machine draws. It withstood, without damage, shipment across the country twice, into Canada and back, as well as many shorter trips in automobile trunks.

Table II. Draw Measurements on Machines Making Wrapping Grades

Machine designation	Basis weight and grade	Wire speed, f.p.m.	Draw, wire to first press f.p.m.	Draw, wire to first press %	Draw, 1st press to 2nd press, f.p.m.	Draw, 2nd press to 3rd press, f.p.m.	Draw, presses to 1st drier, f.p.m.	Draw, 1st drier to 2nd drier, f.p.m.	Draw, driers to reel, f.p.m.	Draw, wire to reel, %
H	Kraft liner	142	+ 4	2.8	+ 2	...	0	0	+ 2	+5.6
J	35-lb. kraft bag	1122	+38	3.4	+ 4	...	− 4	+2	+10	+4.5
K	35-lb. kraft bag	1302	+35	2.7	− 7	...	+21	...	+ 7	+4.3
L	25-lb. kraft	672	+26	3.9	+ 2	...	− 8	0	0	+4.2
M	42-lb. sulphite wrap	680	+16	2.4	0	+4	0	...	+ 8	+4.1
K	40-lb. kraft bag	1302	+47	3.6	0	...	0	...	+ 2	+3.8
J	35-lb. kraft bag	1126	+42	3.7	+ 4	...	−28	+8	+16	+3.7
L	25-lb. kraft bag	660	+20	3.0	− 4	...	0	+4	− 8	+3.6
N	101-lb. card (bl. kraft)	670	+12	1.8	+ 6	...	0	+4	0	+3.6
O	125-lb. mill wrap	120	+ 4	3.3	0	...	0	0	0	+3.3
P	50-lb. wax kraft	492	0	0.0	+12	0	0	...	+ 4	+3.3
K	35-lb. kraft	1116	+25	2.2	− 9	...	+20	...	0	+3.2
Q	52-lb. sulphite wrap	522	− 4	−0.8	+21	...	− 1	+4	− 4	+3.1
P	50-lb. kraft bag	596	0	0.0	+14	0	+ 8	...	− 4	+3.0
Q	74-lb. bl. kraft	294	+ 4	1.4	0	...	+ 4	0	0	+2.7
R	62-lb. kraft	401	+ 2	0.5	+ 3	...	+ 7	−3	+ 1	+2.5
R	17$^1/_2$-lb. bl. sulphite	716	−14	−2.0	+12	...	+22	+7	+ 3	+2.2
H	Kraft liner	288	0	0.0	+ 2	...	− 2	+3	+ 3	+2.1
H	90-lb. kraft	500	+ 8	1.6	− 5	...	+ 1	+4	0	+1.6
H	50-lb. kraft bag	782	+ 6	0.8	+ 6	...	− 6	+8	− 2	+1.5
K	75-lb. kraft	802	+ 4	0.5	+ 4	...	− 4	...	+ 8	+1.5
K	114-lb. kraft liner	470	+ 5	1.1	0	...	+ 2	...	0	+1.5
J	50-lb. kraft bag	890	+10	1.1	+ 8	...	−10	+2	0	+1.1
R	33-lb. kraft bag	815	−16	−2.0	...	...	+24	0	0	+1.0
S	40-lb. sulphite wrap	276	− 2	−0.7	...	...	+ 2	...	+ 2	+0.7

Table III. Draw Measurements on Machines Making Tissue and Toweling

Machine designation	*Basis weight and grade*	*Wire speed, f.p.m.*	*First press speed, f.p.m.*	*Draw, wire to first press %*	*Draw, 1st press to 2nd press, f.p.m.*	*Draw, 2nd press to 1st drier, f.p.m.*	*Draw, 1st drier to last drier, f.p.m.*	*Draw, last drier to reel, f.p.m.*
T	12½-lb. fruit wrap bl.	1016	1016	0	+8	+50	...	0
T	12½-lb. fruit wrap unbl.	1084	1088	+0.4	...	+12	...	0
U	12 ½-lb. fruit wrap	536	528	−1.5	0	+ 6[a]	...	+ 4
V	12.8-lb. fruit wrap	800	812	+1.5	0	−14	...	− 2
W	30-lb. toweling.	914	958	+4.8	0	+ 8[a]	− 76	+ 16
X	11-lb. toilet tissue	1252	1256	+0.3	...	+ 8[a]	− 62	+ 14
X	11-lb. toilet tissue	1212	1212	0	...	+26[a]	− 68	+ 6
Y	33½-lb. toweling	780	766	−1.8	+4	−52	+ 2	+ 6
Z	16-lb. napkin	856	860	+0.5	0	−90	...	+ 12
Z	12-lb. bl. napkin	780	788	+1.0	...	−58	...	− 4
AA	13-lb. toilet tissue	1596	1606	+0.6	...	+ 4[a]	−194	+ 16
AA	13-lb. toilet tissue	1616	1610	−0.4	...	+20[a]	−238	+ 6
AB	13-lb. facial tissue	1344	1336	−0.6	...	0[a]	...	−172
AC	29¼-lb. kraft towel	792	816	+3.0	...	+16[a]	− 80	+ 16
AD	10½-lb. toilet tissue	838	832	−0.7	...	+18[a]	− 8	+ 16
AD	10½-lb. toilet tissue	898	874	−2.6	...	+26[a]	+ 8	− 8
AE	10¼-lb. facial	792	812	+2.5	...	+ 2[a]	...	−122
AB	10½-lb. facial	1734	1766	+1.8	...	+14[a]	...	−282

[a] Yankee drier.

In order to conveniently present the main body of data, it was thought best to tabulate draw measurements in relation to paper grades. Variation in draws or machine speeds, however, is a function of the mechanics of the machine system. Hence these data have been correlated with type of machine drive.

In Tables I, II, and III are shown results of draw tests on machines running newsprint, various wrapping grades, and tissue-toweling grades. Listing in Tables I and II is in the order of decreasing over-all draw (wire to reel) with draw calculated as percentage of machine speed. No two tests on the same machine were made on the same day.

A summation of the speed variation data is shown in Fig. 6. The electric drive, with lineshaft and belt transmission, shows least speed variation, with the

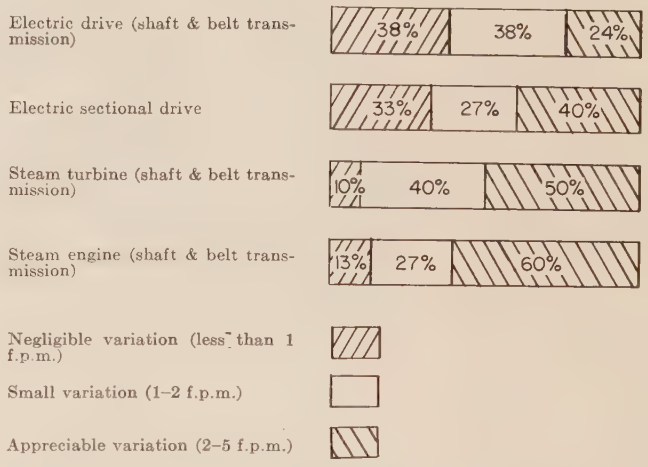

Fig. 6. Speed variation in Crown Zellerbach Corp. paper machines correlated with type of drive

Fig. 5. View of equipment in use measuring speed of a couch roll

electric sectional drive, steam turbine, and steam engine with progressively greater speed variation.

In addition to these results obtained in the paper machine survey, several specific cases were studied. An unbalanced condition was detected in one of the older Yankee driers, indicated by a slight speeding and slowing with each revolution. Correction of this trouble improved operation and allowed machine speed-up. A similar effect was found in a gear-driven couch roll, possibly caused by uneven friction in the couch suction box.

It was observed in a few cases that speed variation, in machines with line shaft drive, did not occur simultaneously in all sections. The large inertia of the drier section, as compared to other machine sections, sometimes caused a delayed response of this section to speed changes with the result that draws at the two ends of the driers varied. This might in some cases be a contributing cause of wet or dry end breaks.

It is believed that the survey of draws and speed variation has been well worth while, and the measuring equipment developed for the purpose will be found of continuing value in papermaking developments and in troubleshooting.

The author wishes to acknowledge the assistance given by Frank Caskey in measurements on the machines in the West Coast mills, and by J. H. Hull in the tests made at the Carthage, N. Y., mill. Mr. Caskey also correlated all of the test data.

Introduction of Stress into a Paper Sheet During Drying

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Quantitative data for stress during drying, shrinkage, and change in moisture content have been determined for various laboratory-made papers. It is demonstrated how the drying of the wet sheet causes shrinkage and if an external restraint is applied how the corresponding stress in the web will change the stress-strain properties of the finished paper. A theory developed by Barkas relating external stress to shrinkage and moisture change in an elastic gel has been applied in order to demonstrate how drying stresses can be calculated, based on thermodynamical data for the sample under test. This theory has proved very useful for the fundamental understanding of the subject. Because paper shows plastic flow, however, introduction of values for volume changes in a paper strip during drying in the theoretical equations gives too large values for the stress. On the other hand, if the larger shrinkage values obtained under no load are used, the stress data calculated agree well with the experimental. The drying stress is sensitive to small changes in the shrinkage during drying. In general, it was found that a total shrinkage of 0.3 to 0.4% will reduce the tension in the sheet by about one half. By drying samples under different stress and later determining stress-strain data it was shown that already small stresses of 1 to 5 kg. per sq. cm. reduce the extensibility of the paper considerably.

THE effect of the drying of paper on its mechanical properties has long been recognized, and several articles directly or indirectly dealing with this subject have appeared in literature during the past 20 years. Changes in the anisotropy of the sheet in regard to tenacity and extensibility when the paper web passes through the drying section were thus described by Robertson and Bailey (*1*). Since then this subject has been studied in greater detail, particularly at the Swedish Forest Products Research Laboratory in Stockholm under direction of Steenberg and Brauns and in the research laboratories of the Wiggins Teape & Co. (1919) Ltd., England, by Rance and co-workers. The phenomenological changes taking place during drying of a wet paper web have been shown to be caused by external restraint on the sheet.

During drying the wet paper web shrinks. If this shrinkage is restrained by application of an external stress, the result will be a build-up of tension in the sheet in the direction of this stress. By stress-strain data taken on paper dried under an increasing amount of tension, it can be shown that the tenacity increases in the direction of tension. Most pronounced, however, is the decrease in extensibility of the paper caused by drying under external stress.

These variables will also have an effect on other paper testing data which are used to characterize the mechanical properties of the product, such as burst, tear, and fold. Wahlberg (*2*) showed recently that tear is a function of the extensibility of the paper and, therefore, is influenced by the drying tension in the web.

Because commercial drying of paper is done on steam-heated cylinders and the wet paper web is supported by the drier felts which press it tight against the cylinder surfaces, the shrinkage during drying is retarded more or less completely. Further, the differential speed between the drying sections determines the dimensional changes in the web, particularly at these points. It is, therefore, to be expected that changes in the draws and felt tensions will have a bearing influence on the anisotropic properties (say, strength data) of the finished sheet. This was also clearly demonstrated in the paper by Arlov and Ivarsson (*3*) based on experimental work on the paper machine at the Central Laboratories of the Swedish Paper Mills. For a literature review in this field, the reader is referred to the articles by Arlov and Ivarsson and by Rance (*4*).

Although we already have much qualitative evidence for the interrelations between the shrinkage of the paper web during drying and the mechanical properties of the final sheet, there is, to the author's knowledge, only very little quantitative data published. Also, a more fundamental theoretical discussion of the relationship between swelling, shrinking, and stress development during drying is needed to better understand the nature of the phenomena that apparently, to such a great extent, determine the properties of paper. An attempt in this direction following thermodynamic equations for swelling stresses in gels developed by Barkas (*5*) will be given in this article. The symbols used in his publications have been maintained throughout.

THERMODYNAMICS OF SWELLING STRESSES

Hydrostatic Stress

As an introduction, let us review the equations governing the thermodynamics of solutions or gels under stress. As shown by Porter (*6*) the hydrostatic pressure increment dp_m necessary to maintain the amount of solvent in a solution constant when the surrounding vapor pressure of this solvent is increased by dh is as follows:

$$s_p \cdot dp_m = v\, dh \qquad (1)$$

Here $s_p = (\delta V/\delta m)_p$ the increase in volume of the solution per unit increase in solvent content at constant hydrostatic pressure p. The equation is derived considering an isothermal thermodynamic cycle with 1 gram of vapor. The symbol v is the specific volume of the vapor at the corresponding vapor pressure h of the solution. In the following we refer to water as the solvent although the equation is quite general to any system when the gel, solvent, and solvent vapor are all present at the same vapor pressure h.

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The index on dp_m notes that we study the changes at constant moisture content m. This is, however, very seldom the actual case because a change in vapor pressure of the water in the surroundings will cause a change in the water content of the gel system studied. In order to find the change in hydrostatic pressure under conditions with varying moisture content in the gel Barkas modifies the equation (1) to

$$s_p \cdot dp = v\left[dh - \left(\frac{\partial h}{\partial m}\right)_p dm'\right] \qquad (2)$$

In comparison with equation (1) it can be seen that the stress p is reduced by sorption.

Here $(\delta h/\delta m)_p$ represents the change in vapor pressure h with a change in moisture content m represented by the slope of the sorption isothermal for the gel under constant stress p. The figure dm' is the increase in moisture content in gram water per gram dry weight. If we write $(\partial h/\partial m)_p = D$ and $(dh/dm') = D'$ where the latter is the slope of the isothermal as determined under the new stress

$$dp = \frac{v}{s_p}(D' - D)dm' \qquad (3)$$

Equation (3) is perfectly general for description of swelling stresses in any gel material providing the deformation is elastic. The hydrostatic stress p is linear to the volume swelling s_p at constant moisture content in the gel, and a set of such $p - s_p$ curves is required to describe the function at various moisture contents m_0, m_A, m_B, etc.

Figure 1 shows principally these stress-strain curves for cellulose based on equation (1) with volume data from Hermans (*7*).

The curves can likewise be regarded as the compression curves of pure cellulose at various moisture contents with the approximation that this material is elastic within the range studied.

Points of equal vapor pressure in the (p, V) curves can be joined by lines h_A, h_B, where $h_A < h_B$ etc. It is shown that the vapor pressure increases both with increasing volume at constant stress p or with increasing stress at constant moisture content m or constant volume V.

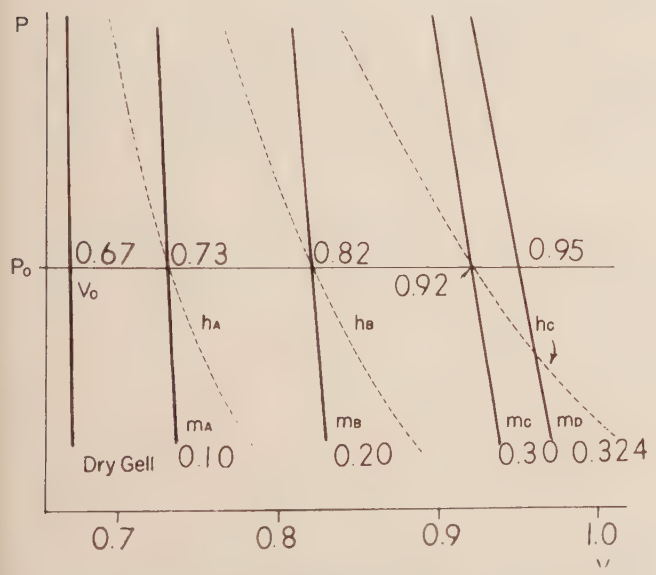

Fig. 1. ***p, V curves for pure cellulose for constant moisture values m and constant vapor pressures h***

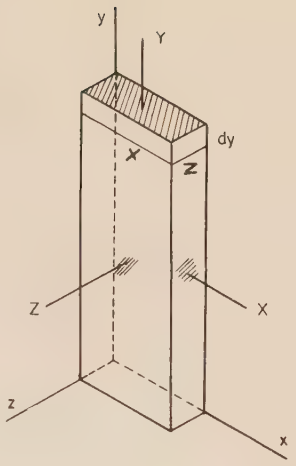

Fig. 2. Directional stresses acting on gel during swelling

Directional Stress

It is often experimentally more convenient to study the gel system under a directional stress instead of under a nondirectional external restraint p. If the corresponding external stresses in the perpendicular directions x, y, z are X, Y, and Z, respectively, it can be shown that, for example,

$$dY_m = \frac{v}{s_y} dh \qquad (4)$$

Where s_y is the differential volume swelling in the y direction

$$s_y = \frac{V}{y}\frac{dy}{dm}$$

for a body $x \cdot y \cdot z$ cm. with the volume V cu. cm. per gram at moisture content m in gram per gram dry substance (Fig. 2). If we take into account changes in moisture content and study the general case with the three directional stresses acting on the gel simultaneously, we find

$$s_x \frac{dX}{dm'} + s_y \frac{dY}{dm'} + s_z \frac{dZ}{dm'} = v(D' - D) \qquad (5)$$

with symbols as before.

The change in directional stress

$$\Delta Y = \frac{v}{s_y}(D' - D)\Delta m' \qquad (6)$$

where s_y is the volume swelling in the y direction when all stresses X, Y, Z are kept constant simultaneously.

Barkas has advanced this theory of thermodynamics and applied it for analysis of swelling stresses in wood, published in a series of excellent articles recently concentrated in a monograph by Meredith (*8*).

EXPERIMENTAL PROCEDURE FOR DETERMINATION OF SWELLING STRESS DATA

In order to study a given gel material for the equations derived, it will be necessary to obtain experimental data for the external stress p or directional stress Y at corresponding volume change s. Further, it is necessary to follow the corresponding changes in moisture content. Preferably the experiment could be done at constant humidity and the moisture adsorption

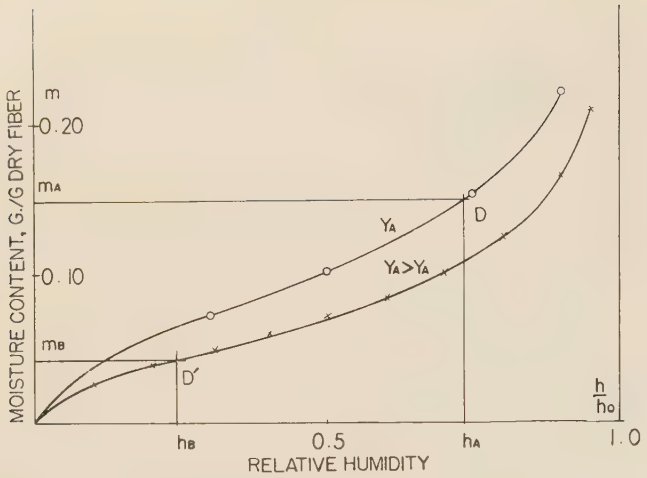

Fig. 3. Moisture adsorption–vapor pressure diagram; the lower curve gives data for sulphite cellulose at 25°C. and atmospheric pressure p_0

and swelling measured as a function of varying restraint. Further data can be obtained by studying the shrinkage during drying with the gel under known varying or constant stress and simultaneously determining the change in moisture content. In a drying experiment the vapor pressure in equilibrium with the gel will not be constant but will decrease because of the decrease in moisture content. For each value of stress the moisture content m of the gel varies with vapor pressure h according to the moisture adsorption isothermal, Fig. 3. The testing data, naturally, also depend on temperature T which determines h_0 and the corresponding value for specific volume v.

Assume that we study a cellulose gel during water removal from a moisture content of m_A based on dry cellulose to a moisture content of m_B at the corresponding vapor pressures h_A and h_B and the change in stress on the gel is the difference between Y_A and Y_B. This means that we move from point D on the upper isothermal in Fig. 3 to point D' on the lower isothermal. The vapor pressure–moisture adsorption diagram should be valid for the corresponding temperature T at which the experiment is done.

APPLICATION TO DRYING STRESSES IN PAPER

For information about the stresses developed in a paper web during drying, experiments have been run in which the samples are fixed moist between the clamps in an automatic stress-strain recorder. The lower clamp is connected to the straining mechanism, and the upper, to a stress recording strain-gage transducer. Experiments of this type on paper have previously been published by Steenberg and Ivarsson (*9*), Lyne and Gallay (*10*), and by Rance (*4*). The advantage of an automatic instrument for studies of this type is obvious.

The upper curve in Fig. 4 shows principally the form of a stress-drying time diagram obtained from a beaten bleached sulphite paper. Previously published diagrams show the same typical S form. After a slowly increasing slope during the first part of the drying cycle, the developed stress soon rises rapidly through an inflection point and finally reaches a maximum value $Y_{max.}$

Experimental Data

Preparation of Samples. Handsheets 125 grams per sq. m. were made from bleached sulphite pulp beaten to various free shrinkage values. The beating was done in a Valley laboratory beater, pulp concentration 2%, weight on bedplate 4 kg. The handsheets were pressed to a maximum pressure 5 kg. per sq. cm. Standard laboratory equipment was used. The values for free shrinkage represent the average linear shrinkage obtained during drying in an oven at 105°C. without other external stress than the own weight of the handsheet. To compensate for small variation in shrinkage in the different directions in the plane of the paper, the handsheets were marked when wet with points along a circle of known diameter. After drying, ten measurements of the diameter in various directions were taken, and the arithmetic average $\bar{s}_f$ was calculated. These data are used here to characterize the state of beating of the pulp used for the paper samples.

After pressing, the handsheets were kept wet between blotting papers with an average moisture content of 4 grams water per gram dry fiber.

Drying Conditions. Before we further describe the experimental work done, the effect of some important testing variables should be discussed. First, it should be pointed out that it is of little importance how the energy is submitted to the sample. Therefore, any type of drying as infrared, high frequency, or regular air will give the same result. The developed stress in a given sample theoretically depends only on the change in moisture content and the amount of shrinkage allowed. The drying conditions are further characterized by the values of vapor pressure h and specific volume of vapor v; both of which are related to the temperature T by the common gas law

$$vh = nRT$$

Consequently, the time of drying would have no effect on the result. This is, however, strictly true only for an elastic gel. Now, it is known from mechanical studies on paper that this material exhibits viscous properties also and it was, therefore, necessary to study how the paper samples would respond to variation in drying time.

Two experiments showing the drying stress developed at constant length of the sample during drying with infrared heat at 60°C. to a moisture content of 4% (curve A) and with moist air at room temperature to a

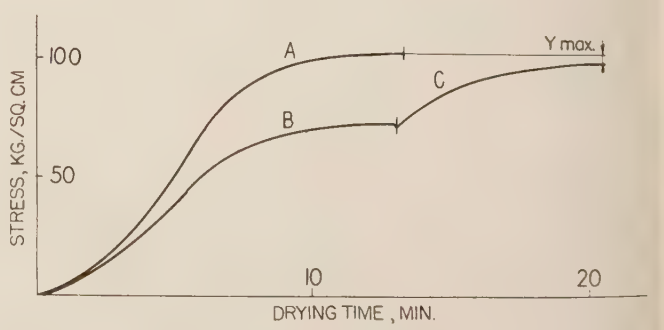

Fig. 4. Stress at zero shrinkage as a function of drying time; curve A, infrared heat 60°C. to m = 0.04; curve B, air drying to m = 0.09 followed by infrared drying to m = 0.04, curve C

moisture content of 9% (curve B) are shown in Fig. 4. If the experiment B is followed by infrared heat drying to the moisture content of 4% as in case A, the final stress will be almost the same. Several experiments of the same type have shown that the difference in stress, if present, is small. In the experiment mentioned the difference in total drying time was quite small. However, the stress does not change if the drying time is extended over a range of 25 min. as shown by some numerical data in Table I.

Table I. Drying Stress at Different Drying Times

Drying time, min.	*Stress, units*
4.3	5.2
4.8	5.0
5.8	6.2
8 5	5 7
15.0	5.2
15.5	5.9
24.0	5.2

The result should not be interpreted as valid in general for any sample at any length of drying time, but it is shown that the time is not as critical as might have been expected from the realization that a moist paper web is quite plastic.

Because the drying stress must be interpreted as a combined result of stress built up because of shrinkage of the cellulose gel and a simultaneous reduction of this

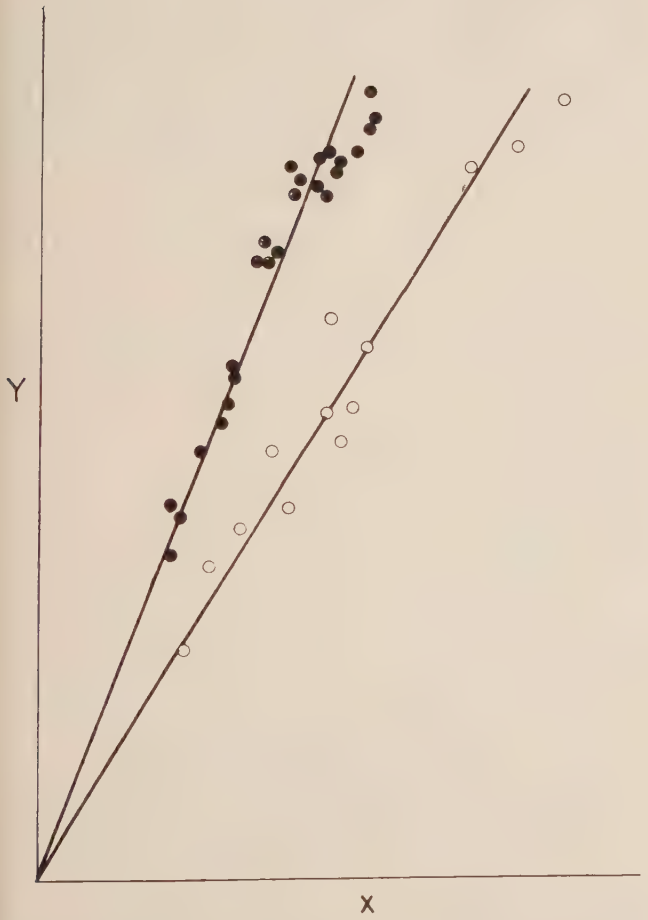

Fig. 5. Drying stress Y for various width x of paper sample; lower curve unbeaten pulp, upper curve beaten pulp

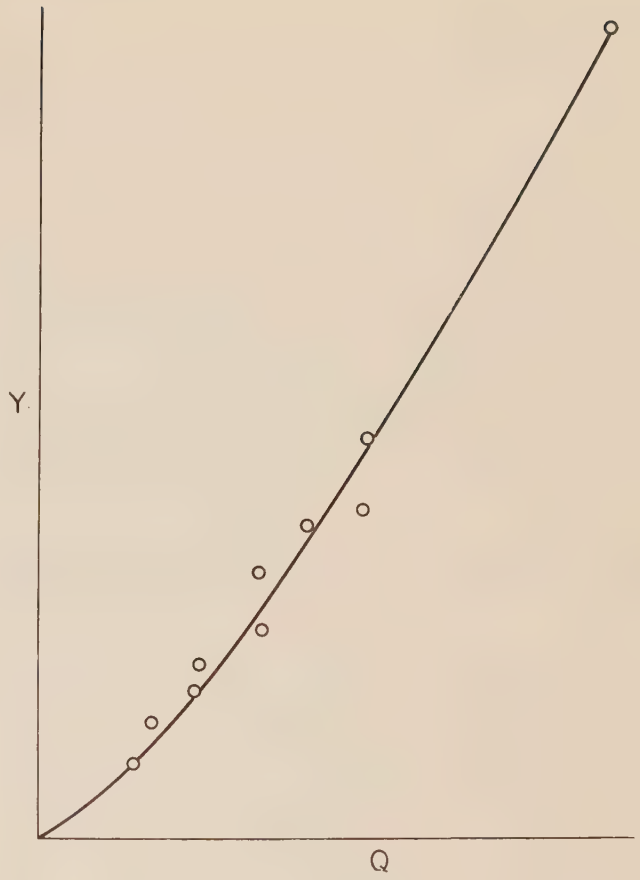

Fig. 6. Drying stress Y as a function of basis weight Q corrected for density

stress due to viscous flow (relaxation of stress), it could be expected that if the drying takes place slowly, the paper will be in continuous elastic equilibrium with the drying stress. This is actually an experimental fact. If the drying experiment continues from the point of maximum stress, the sample shows no or very little relaxation of stress. This is indicated in Fig. 4, curve A.

Sample Dimensions. Determinations of drying stress for samples of various widths, lengths, and weights have been run. Some data for paper of beaten and unbeaten pulp are plotted in Fig. 5. The force is directly proportional to width of the strip (cross-sectional area) as could be expected.

Corresponding stress data have been recorded for handsheets made from the same pulp but with various basis weights. Although the pressing was done under same load per unit area, the density of the sheets varied slightly probably because of differences in sheet formation. Thus the area of the sample as tested, xz, is not linear to the weight of the sample. On the other hand, if a correction for density is done, the drying stress is almost proportional to the weight of the sample unless the sample is very light. (Fig. 6).

For an elastic gel the stress during drying should be independent of the sample length. If there is plasticity involved under deformation, however, the stress might vary with the length of the sample. Compare stress-strain curves from different length paper strips. This subject has been studied in detail by Andersson (*11*). In general, we have found that the longer strips give larger drying stress. The data presented in this work

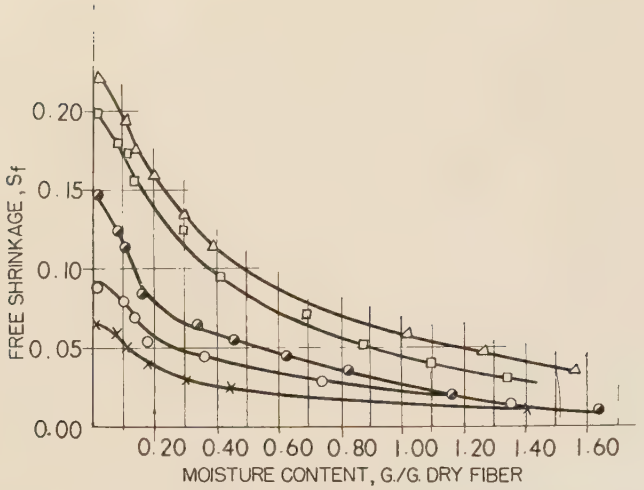

Fig. 7. Free shrinkage-moisture content diagrams for bleached sulphite pulp at various amounts of beating

have all been obtained from 8 to 10-cm. samples, the sample length being constant in each series of tests.

As a summary, it might be concluded that in all work of this kind a complete description of the sample tested and the testing conditions is necessary. Each paper sample should be regarded as a separate cellulose gel with its own individual properties.

Shrinkage-Moisture Diagrams

The shrinkage obtained during drying depends on the change in moisture content. If the shrinkage is studied without any external stress, shrinkage versus moisture content diagrams of the type shown in Fig. 7 can be drawn. This diagram shows how the amount of shrinkage increases with decreasing moisture content and also how beating increases the shrinkage properties of the cellulose fiber. The intersections between the curves and the vertical axis in the diagram represent the total free shrinkage when the samples are completely dried.

The slope of the $s_f - m$ curves varies from sample to sample. The paper obtained from less beaten pulp shows a different rise in the slope of its shrinkage curve in comparison with more beaten pulp. Consequently, a paper made from well-beaten pulp will begin to shrink at comparably higher moisture contents. This also has been pointed out by Rance (*4*), and the findings are apparently in accord with theories regarding the effect of surface tension on paper web shrinkage. This surface tension force will promote a contraction of the paper web at moisture contents much above the one at the fiber saturation point.

Drying Stress-Moisture Diagrams

From equation (6) it can be expected that if two gels with the same density are studied, the one that shows more shrinkage for a given change in moisture content will develop proportionally less stress during drying. In general, it can, therefore, be expected that the shape of the shrinkage versus moisture curve will be depicted in the stress versus moisture diagrams. This is even better realized when we remember that the moisture adsorption versus vapor pressure isothermal does not change appreciably because of beating.

If the corresponding drying stress Y versus moisture content m curves are plotted for the samples studied in Fig. 7, curves of the type shown in Fig. 8 are obtained. In general, this diagram indicates that when the pulp is more beaten the paper has a stress-moisture content diagram with its vertex farther away from the origin of the diagram. This means in practice that when the paper is dried the stress developed will increase relatively much faster after the moisture content corresponding to the vertex mentioned is reached. More beaten pulp will give paper that begins to develop drying stresses at relatively higher moisture contents than paper from less beaten pulp.

When corresponding data for drying stress Y and length shrinkage during drying s_y are studied, it is convenient to represent the result in the form of $Y - s_y$ diagrams in analogy with the $p - V$ curves (Fig. 1). Such data for the bleached sulphite pulp studied in this article are shown in Fig. 9. Points on the various curves representing identical moisture contents have been connected with fine lines. Because the data for s_y have been obtained at various constant stress levels, the diagram indicates how much the web must be allowed to shrink if this stress should not be exceeded. As an application, it gives information about the differential speed required in a drying section for any changes in stress or moisture content.

An analysis of Fig. 9 shows that for a given stress more allowance to shrink has to be given the moist paper between m = 10–20% than between any other moisture ranges of 10%. This is in agreement with data obtained from actual machine runs, Arlov (*3*). On the other hand, if small stresses during drying affect the paper's final properties, also the shrinkage at the higher moisture ranges have to be taken into consideration. It is interesting to note how small the amounts of shrinkage are, that, if allowed, prevent in-

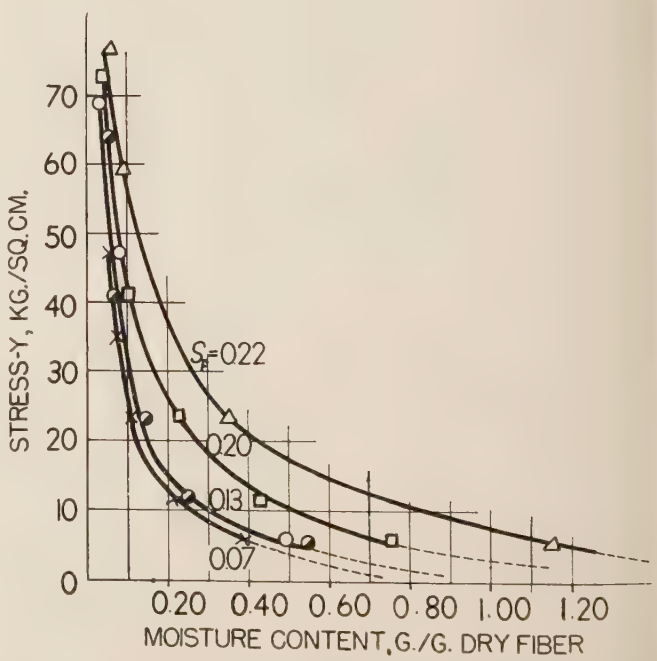

Fig. 8. Drying stress-moisture content diagram for bleached sulphite pulp at various amounts of beating indicated by s_f

troduction of drying stress, or considerably reduce it. For example, a total shrinkage of 1% reduced the stress for $s_f = 0.06$ paper to 17% and for $s_f = 0.19$ paper to 31% of $Y_{max.}$ Shrinkages of 0.3 to 0.4% are enough to reduce the drying stress by one half. This shows quantitatively the effect of a mechanical strain large enough to change the fine structure of the gel (fibrils) but too small to orientate the fibers themselves.

Numerical Calculations

The dimensions of equation (6) are stress per unit area.

By multiplying with the cross-sectional area A of the sample and remembering that

$$s_y = \frac{V}{y} \cdot \frac{dy}{dm}$$

we find for a small change in moisture content Δm and corresponding change in directional swelling Δy:

$$\Delta Y = \frac{v(\Delta m)^2 \cdot Q \cdot h_A}{\Delta y} (D' - D)c \qquad (7)$$

where Q is the weight of the dry sample, c a scale constant for the $m - h$ diagram and D' and D the actual slopes of the moisture adsorption isothermal. The value of D should be taken at h_A.

Some numerical data obtained by taking $\Delta y =$ the changes in free shrinkage of the gel are given in Table II. Because paper flows under stress corresponding

Table II. Comparison Between Calculated and Experimentally Found Data for Drying Stresses; Sulphite Pulp Handsheets, Various Beating, Data from Figs. 7 and 9

Sample s_f	m_A	m_B	Δm	D′ − D	Δy, *cm.*	ΔY *kg./cm.² calc.*	ΔY, *kg./cm.² found*
0.09	0.10	0.04	0.06	1.41	0.07	15	19
0.15	0.10	0.04	0.06	1.41	0.22	5	23
0.15	0.20	0.04	0.16	3.26	0.54	31	42
0.22	0.10	0.04	0.06	1.41	0.18	6	18
0.22	0.30	0.04	0.26	3.63	0.79	63	49

$v = 4.34 \cdot 10^4$ cu. cm./g. $h = 32$ g./sq. cm. $Q = 0.052$ g. D' and D values obtained from diagram, Fig. 3.

experimental Δy values give too high figures for ΔY. The approximation is theoretically better the smaller the actual stress is and seems to be feasible.

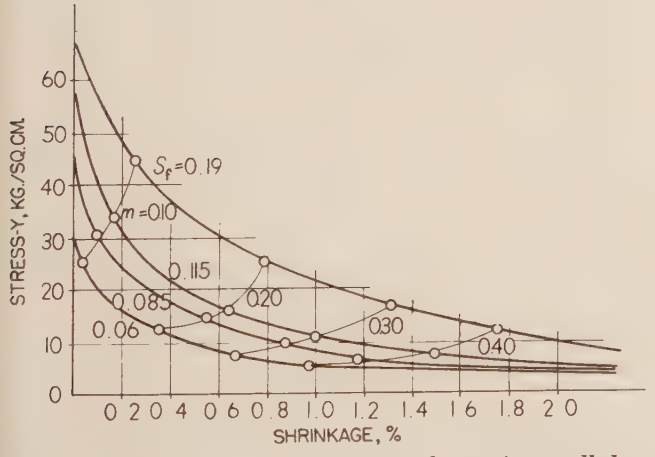

Fig. 9. Load-deformation diagrams for various cellulose fiber gels (paper); deformation data are given as per cent shrinkage on the horizontal axis; data for same moisture content are combined with fine lines

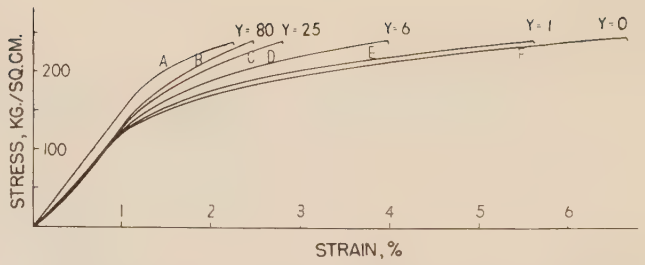

Fig. 10. Stress-strain diagrams for bleached sulphite laboratory handsheets with $s_f = 0.20$ taken after previous drying at various stress Y; the diagram shows the effect of drying stress on extensibility of paper

Generally the calculated data agree well with the experimentally determined data.

EFFECT OF DRYING STRESS ON STRESS-STRAIN CURVES OF PAPER

Knowing quantitatively the stress introduced during drying of the paper samples described, it is now of interest to study how these stresses affect the mechanical properties of the same papers. In order to do this, samples from the same wet sheet were dried under tension at various stress levels to a moisture content of 4%. After conditioning, the stress-strain diagrams were taken at 50% R.H. and 25°C. These curves are reproduced in Fig. 10. Curves B-F represent paper dried previously at a constant stress Y of 80, 25, 6, 1, and 0 kg. per sq. cm. dry cross-sectional area, respectively. There is very little change in the stress at rupture, but the drying stress causes a pronounced reduction in the corresponding strain figures. Also, it should be pointed out that the drying stress required to cause this change in properties is quite small. The draws in a paper machine usually represent a much greater stress than the Y values for curves E and F. This explains why it is practically impossible to commercially make a paper with a machine direction characteristic as represented by curves F and E in Fig. 10.

That the effect of stress during drying on the properties of the final paper is analogous if not identical to the effect of stress applied to the sample in a stress-strain test is shown by curve A in the same figure. This curve is taken from the same sample as F but after two loading cycles to a stress of 80 kg. per sq. cm. Curves A and B are practically identical.

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Effect of Water Removal on Sheet Properties

The Water Evaporation Phase

HERBERT F. RANCE

The mechanism of web contraction during drying is discussed in an attempt to establish a roughly quantitative relation between the sorption properties of the individual fibers and the structure and behavior of the paper sheet. A clear distinction is drawn between web contraction due to surface tension between fibers and that due to fiber shrinkage. It is suggested that inter-fiber contraction within the main plane of the sheet is largely irreversible, whereas intra-fiber contraction is largely reversible and can be roughly estimated through the water expansivity of the dried paper. Bonding between fibers plays a vital role in fixing inter-fiber contraction and in transmitting intra-fiber shrinkage to the web. A third type of web contraction due to the twisting of fibers on drying, is postulated to account for anomalous reversibility of the contraction of webs made from unbeaten stock. Intra-fiber web contraction is held to be a major cause of structural distortions which are the source of a great part of the extensibility of freely shrunk paper. This shrinkage-induced extensibility manifests itself through straightening of crumpled fibers with consequent breaking of fiber/fiber bonds. Reinforcement of bonds by use of amino resins can eliminate shrinkage-induced extensibility. The effect of drying tensions on water expansivity, extensibility, and tenacity is discussed. Drying tensions affect the shrinkage and expansion of paper only over a moisture range corresponding to original conditions of application of tension. Tenacity caused by drying tensions is due to enforcement of a tighter bonding pattern, with consequent avoidance of piecemeal disruption. The influence of fiber orientation on this pattern of effects is discussed. Complete orientation leads to a pattern of properties clearly distinguishable from that obtaining with randomly oriented paper dried under machine tension. Partial orientation introduces extra complications. More research is needed to check the suggested trends and to verify the validity of quantitative estimates.

It is one of the paradoxes of papermaking that removal of the last traces of the making water has the most profound effects on the nature and structure of the forming sheet. The initial suspension of fibers usually contains about 100 parts of water to 1 part of cellulose. Removal of the last 2 or 3 parts of this hundred is very difficult—it has to be evaporated off in a most expensive manner. Even more important is the fact that the structure, strength, and behavior of the finished paper are largely determined by events occurring during removal of the last fraction of a part of water, after the water content has already been reduced to about one third of the weight of the fiber. Before this point, the web is still a loose assemblage of unbonded fibers. After this point, it becomes a composite structure in which the fibrous elements lose their identity and merge their properties into the surrounding whole.

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The fixing of the structure and properties of the web during the water-evaporation phase is accompanied by measurable changes in the dimensions of the web, which have a direct bearing on the structural character of the composite sheet that is emerging. These changes merit greater attention than they have so far received for they are the key to an understanding of many of the interwoven complexities of structure and behavior exhibited by a sheet of machine-made paper. Although it is over 20 years since Campbell's classic contribution (*1*) to the subject of web shrinkage, and nearly 20 years since Larocque's pioneer investigation (*2*) into the hygroinstability of paper, the field remains largely unexplored, and there has been no concerted attempt to determine the interrelations of these associated phenomena.

This paper is an attempt to indicate the general pattern of interrelation between events during drying and the consequent paper properties. Although the treatment is largely qualitative, a roughly quantitative basis for the trends has been indicated by drawing upon data obtained in a wide variety of studies designed originally for various *ad hoc* problems. It is hoped that this treatment may stimulate more precise researches designed directly for investigation of the fundamental aspects of this technologically important subject.

THE CAUSES OF WEB CONTRACTION DURING DRYING

At the entry to the drying section of the paper machine, the web has a water content usually about twice the weight of the solids. Most of this is loosely held between the fibers, but a small quantity, about one quarter of the weight of the cellulose fibers, is held within the fibers as water of swelling. These two types of water must be clearly distinguished, though in practice there is not always a clear separation between corresponding successive phases of water removal.

The process of papermaking is largely a process of web consolidation. At the earlier stages, this has been effected through drainage, suction, and applied pressure. At the beginning of the evaporation stage, consolidation caused by applied external forces is succeeded by a consolidation operated by forces arising *within* the web from the surface tension of the diminishing water links between the entangled fibers. The role played by surface tension in causing the web to contract at this critical stage has been explained in detail by Campbell (*1*). The reduction of this effect can be readily demonstrated by the bulking effect produced by adding to free beaten stock, materials which reduce surface tension.

This consolidation due to drawing together of the

fibers by surface tension clearly belongs to the phase of removal of free water; it is succeeded by yet another phase of consolidation, when the "bound" water, the water of swelling of the cellulose fibers, begins to evaporate. When this occurs the individual fibers shrink, their volume shrinkage down to 65% R.H. being around 19%, corresponding to a diameter shrinkage of around 10%, while the fiber length is virtually unchanged. Simultaneously, the fibers attempt to coil and twist in the way familiar to the microscopist observer of drying cellulose fibers.

The stated value of 19% volume shrinkage requires some explanation. In this paper an attempt will be made to relate, in a crudely quantitative fashion, the shrinkage/swelling characteristics of a paper web with the corresponding characteristics of the component fibers. An immediate obstacle to this attempt is a lack of precise quantitative knowledge as to the shrinkage/swelling characteristics of the component fibers involved. There is an extensive literature, comprehensively reviewed by Stamm (*3*), Valko (*4*), and Gallay (*5*), dealing with water sorption and dimensional change of cellulose fibers up to saturation point, but there are complicating factors affecting the selection of relevant data. First, there is the complication due to structural cavities within the cellulose. These can increase the sorbed water content beyond the point of saturation of the fiber walls [Stamm (*3*)]. Second, there is the irreversible loss of hygroscopicity attendant on the first few cycles of drying and wetting. In the work to be described here, the fibers (woodpulp) had always been air dried once since digestion, before the experiments started, so due account must be taken regarding this factor. The fiber saturation values assembled by Stamm (*3*) for various wood pulps, range from 25 to 30% by weight. These values do not include water held in structural cavities. Some at least of the values refer to slush-pulp fibers (i.e., undried since digestion). Seborg *et al* (*6*) give an example where the saturation content for such a pulp (hemlock sulphite) was irreversibly reduced from 28 to 24% by once drying, to 22% by twice drying, and to a minimum level of 20% after six or more dryings. Heath and Johnston (*7*), using an isotherm extrapolation derived from Hailwood and Horrobin (*8*), have calculated moisture regain values at 100% R.H. and 73°F. for various papermaking fibers predried over phosphorus pentoxide. Their values for total water content range up to 25 % by weight with many values around 22% for a wide variety of wood pulp fibers.

The web shrinkage and expansion data to be discussed here refer to sorption changes between saturation and equilibrium at 65% R.H. and 70°F. At this condition, cellulose fibers contain around 9% water, judging from the data assembled by Stamm (*3*), and those given by Heath and Johnston (*7*).

Summing up the various published data, it is proposed to accept a mean value of 15% for water sorbed between 65% and fiber saturation for the air-dried pulps considered here. Since these pulps are of different types (sulphite and sulphate wood pulps), this mean value can in any case only be an approximate reference point. If it is now assumed that this water is sorbed without appreciable loss of total volume, then it corresponds to a volume swelling of 24%, calculated on dry volume. Inversely, this corresponds to a volume change of 19%, calculated on wet volume.

The assumption that there is no appreciable loss of total volume, and that there is a consequent equivalence between volume of water sorbed and external dimensional change, may be queried. Weidner (*9*) has recorded findings which support the assumption for humidities up to 85 to 90% R.H. but, for higher humidities he reports fiber diameter increases smaller than the corresponding volumes of water sorbed. On the other hand, Stamm (*3*) has summarized a considerable amount of data supporting the view that there is a close equivalence between volume change and water sorbed up to fiber saturation point. In this context, it is of interest to record some recent determinations of the dimensional expansion of a paper sheet which have shown that this is linearly related to the amount of water sorbed, up to a 19% water content at 95% R.H. These data, which relate to paper made from free-beaten sulphate pulp, are presented in Fig. 1. Disregarding at this stage the mode of relationship between degree of fiber swelling and degree of paper expansion, the linear character of Fig. 1 supports the general thesis of assumed equivalence between volume change and quantity of water sorbed. In the absence of more precise data, the pros and cons for higher or lower values could be debated indefinitely; for the purposes of this paper, the position will be determined by acceptance of 19% as a typical fiber-volume shrinkage due to water desorbed between saturation and 65% R.H. (equivalent to a 10% diameter shrinkage).

It is assumed throughout that fiber length changes in sorption and desorption are negligible, and that the shrinkage and swelling are manifested primarily in the cross section of the fiber.

Note that the degree of swelling of cellulose in the present context must not be confused with degrees of "swelling" determined by various dilatometric, centrifuging, or water permeability methods which have been reviewed by Gallay (*5*). With all those methods, a considerable amount of inter-fiber water is included in the determination; though the methods have their specific relevance in other contexts, they are inapplicable here. The "fiber saturation" values employed here refer essentially to swelling of the fiber wall material as such, and do not even include the filling of structural cavities within the wall.

MECHANICS OF INTER-FIBER WEB CONTRACTION

At the beginning of evaporation, the fibers lying in the surface layers are pulled inward to effect a compaction within the thickness of the web. At the same time, each of these surface fibers is subjected to a sideways pull toward its neighbors, so that there is from the outset a slight lateral contractive force. With a web made from very wet-beaten stock, the only air/water interface throughout the drying process is at the surface boundaries of the web, and in effect this interface acts as a contracting envelope, dragging the aggregate into a more compacted form. Resistance to thickness contraction sets up a hydrostatic negative pressure within the water medium, thus distributing the contractive forces evenly throughout the mass and

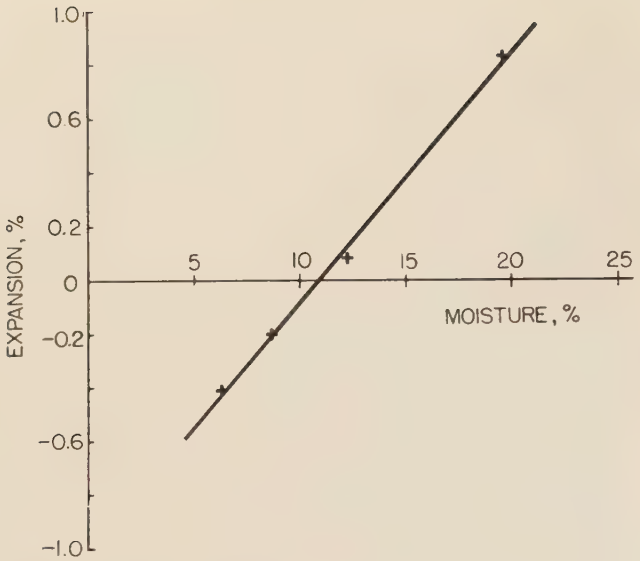

Fig. 1. Relation between sorbed water content and expansion of paper

reinforcing the lateral contractive force. Then the web contracts as a whole as though it were a composite body. The sequence of events is somewhat different with a web made from free-beaten stock, since air enters such a web at an early stage, and as indicated by Campbell, the net contractive force acting on the web can be regarded as the aggregate of the contractive forces of the diminishing water bridges between individual fibers. In all cases, the basic mechanism is the same, the contractive force being derived directly from the surface tension of the evaporating water medium in which the fibers are dispersed.

The permanence of the consequent contraction depends on several factors. If there is sufficient lubrication between the fibers, then some part of the contraction may involve sliding of the fibers over one another, to give denser packing without any deformation of individual fibers. This part of the contraction may be regarded as truly permanent and irreversible. Another part of the contraction, however, may involve distortion of the individual fibers, and this cannot be fixed permanently into the structure of the drying web unless adhesive forces between the fibers are sufficient to hold the strained fibers in the positions to which they have been drawn by surface tension of the water which has been evaporated.

These considerations show that the degree of surface tension contraction that can be fixed in the web is at its lowest when the fibers are long, strong, and incapable of forming fiber-fiber bonds. Fiber length inhibits packing caused by unhindered sliding of the fibers toward one another. Fiber strength provides recovery forces tending to reverse any packing that involves distortion of individual fibers; and, in the absence of bond formation between fibers, there is no force to oppose the recovery forces arising from individual fiber distortion, once the final layer of free water has evaporated. For these reasons, the web contraction caused by surface tension between fibers is at its lowest with unbeaten stuff, where both the length and the strength of the individual fibers are unimpaired and where the undamaged surfaces of the fibers are incapable of bonding together.

Conversely, permanent web contraction during the phase of free water evaporation is progressively encouraged b ally of the physical effects of beating. Fiber shortening facilitates unhindered sliding of the fiber particles as they are pulled toward one another by the diminishing water bridges. Internal bruising of the fibers, resulting in reduced cohesion between the constituent fibrillae, reduces the bending rigidity of the fibers, and hence reduces the force of recovery in any fibers distorted by the surface tension compaction: and surface exposure of swellable cellulose promotes fiber-fiber bonding which helps to fix the fibers in the positions to which they have been drawn. At the same time these processes of fiber shortening and fibrillation progressively increase the water/cellulose surface area, thus providing an increase in the total force of compaction in addition to providing conditions favorable to the fixing of that compaction in the web.

One consequence of this is the recorded observation that a web made from wet-beaten stock can contract to a considerable degree, long before the water content is reduced to a point where the individual fibers begin to shrink. Indeed, the water content at which contraction begins, rises progressively as the degree of beating rises, as demonstrated in experiments where the contraction tensions of drying webs were recorded during evaporation of the water [Rance (*10*)].

On the other hand, the start of web contraction can be considerably retarded by physical hindrance. Pritchard (1954) has recently published the results of some laboratory sheetmaking experiments on sulphite pulp beaten to different degrees, which show the effect of normal pressure applied to the web during the surface tension contraction phase. Figure 2 summarizes the results obtained. The total linear web contractions have been plotted against final sheet density, for each level of applied pressure (broken lines), and isometric lines have been drawn in representing each degree of beating. With free beaten stuff, where the web contraction normally does not enter until a later stage, the applied pressure had little effect on planar contraction, though it had a considerable compacting effect in the thickness of the sheet and hence on the sheet density (see horizontal isometric lines). With

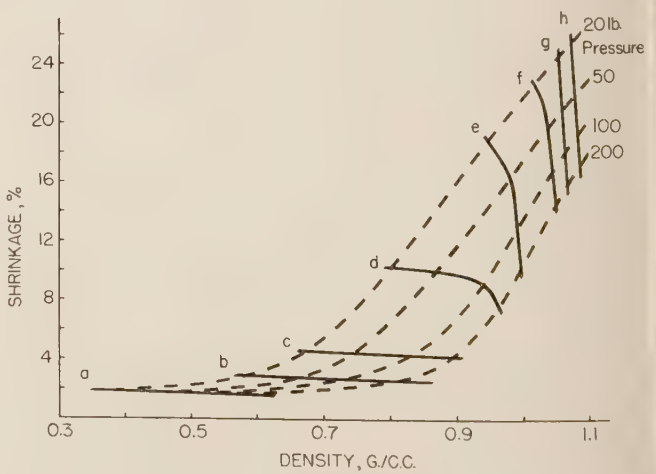

Fig. 2. Effect of pressing on density (Pritchard)

A—disintegrated only. b—beaten 15 min. c—beaten 30 min. d—beaten 1 hr. e—beaten 1½ hr. f—beaten 2 hr. g—beaten 3 hr. h—beaten 4 hr.

wet beaten stuff, pressure had little effect on thickness or final sheet density, presumably because the internal contractive forces were great enough to take charge and thus made pressure redundant in this respect; but the pressure did exert considerable hindrance on the planar contraction of the wet-beaten webs, presumably by preventing the web contraction which otherwise would have occurred at the high water contents during pressing.

MECHANICS OF WEB CONTRACTION DUE TO INTRA-FIBER SHRINKAGE

The mechanics of the second phase of web contraction due to the shrinkage of the fibers themselves, are less obvious than those of the phase of surface tension contraction. Some writers have tended to treat the two phases as virtually identical—as manifestations of the same phenomenon at different ranges of dimension. On this view, the phase of surface tension contraction between macroscopic particles is considered to extend to a lower range of pore or capillary size, ultimately merging into a range of dimension appropriate to the "pores" or the cellulose itself. On the same view, the swelling of cellulose is seen as capillary adsorption and penetration of liquid water within the "pores" of the cellulose, which is thus "prised" open to larger dimensions.

The writer considers this view to be inadequate as an explanation of fiber swelling, and misleading in the context of web contraction and paper expansion, in that it blurs over some essential distinctions between the two phases of contraction. First, it ignores the fact that the fibers and fibrous particles, and consequently the capillary and pore spaces between them, belong to a gross order of dimension far distant from the molecular order of dimension involved in cellulose swelling. This is so even when the cellulose is finely fragmented and fibrillated under mechanical treatment.

Second, it ignores the fact that the forces binding sorbed water to cellulose are molecular forces of attraction with a considerable energy of bonding, as evidenced by the heat of sorption. This provides a source of energy for the swelling of cellulose which

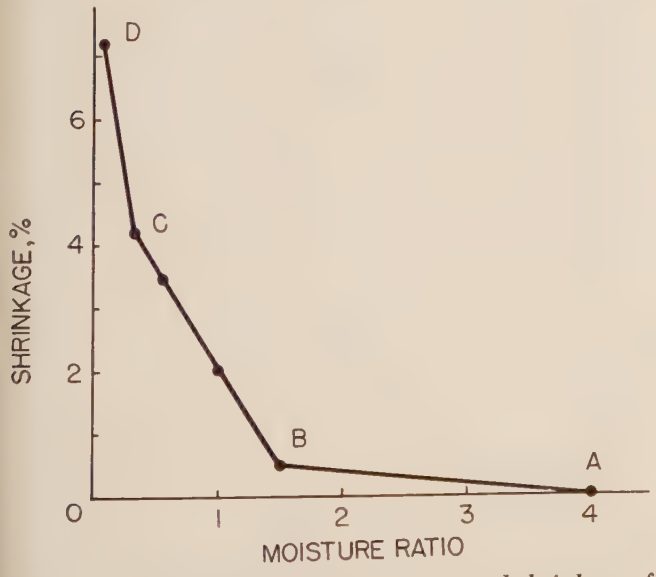

Fig. 3. Relation between water content and shrinkage of wet web

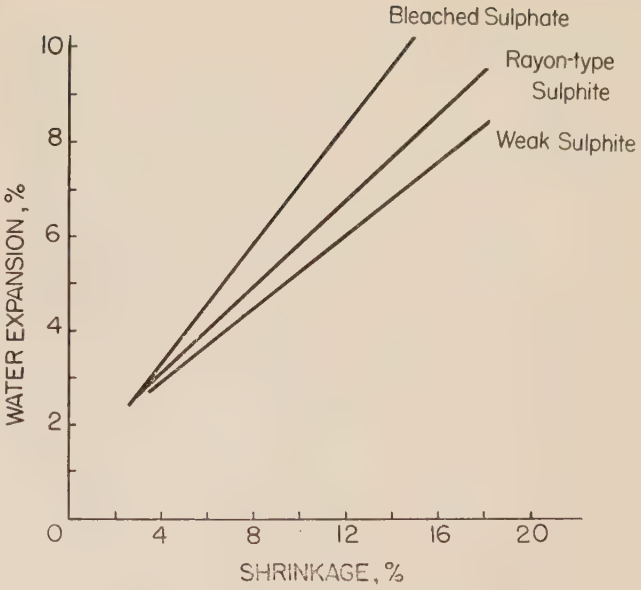

Fig. 4. Relation between water expansion and shrinkage

has no parallel in surface tension phenomena. The wetting of a porous medium provides no such energy to effect swelling. Valko (*4*) has indeed pointed out that capillary condensation of water within cellulose "pores" might be expected to cause cellulose to *shrink* when exposed to water vapor, if we view the matter solely in terms of surface tension. Hermans (*12*) has argued against the view that cellulose takes up water through adsorption on internal surfaces. He has presented a strong case for viewing the sorption primarily in terms of volume solution of water in cellulose, a process of the same type as the solution of water in sulphuric acid, and not of the same type as absorption into a sponge, except as a distant analogy. He is prepared to admit the possibility of capillary condensation at higher water contents, corresponding to the steepening of the sorption curve, though he shows that this steepening also is perfectly consistent with the trend of normal solution following Raoult's law. Barkas (*13*) also emphasizes that it is unrealistic to visualize capillary menisci at molecular dimensions and insists on a clear distinction between molecular sorption and capillary sorption. He suggests that capillary water must all have evaporated before a humidity of 70% is reached on drying, though he visualizes a region of overlap between the two effects.

Stamm (*14*), following Babbitt (*15*), has recorded the still more extreme view that up to a relative vapor-pressure of 0.99 the whole process of water sorption may legitimately be regarded as molecular in type. These views, which the writer shares, serve to narrow down the possible range of overlap between the inter-fiber and intra-fiber phases of web contraction.

The essential distinction between these two phases of web contraction has been demonstrated by some measurements of the linear dimensions of a wet web during water evaporation on a paper machine. The stock was very wet beaten, thus providing favorable conditions for overlap between the two phases if such overlap can occur. In Fig. 3 the cross-direction web shrinkages (linear) have been plotted against the amounts of water remaining in the web at each stage

of measurement. The resultant plot exhibits three clearly defined stages. First, from A to B a considerable amount of water is removed ($2^1/_2$ times the weight of cellulose) with a negligible planar web-contraction. This evidently corresponds to an initial stage of surface tension contraction within the thickness of the web, terminating at B when resistance to further thickness contraction sets up forces of planar contraction strong enough to overcome area restraint B-C corresponds to this second stage of surface tension contraction when the web contracts both in thickness and in area. During this stage there is a loss of water greater than the weight of the cellulose, so it is clear that there must be a continuing thickness contraction in addition to the 4% linear contraction. Finally at, or soon after C there is a sharp steepening of the curve, corresponding to a water content of 33% (or less). Note that four points lie precisely on the straight line BC, so there can be no doubt that a sharp change of slope does occur at, or after, C. After C, the web contracts by a further 3% through a water loss of only 25% of the weight of the cellulose. The cross-direction shrinkage of the web on this machine was, to a considerable extent, hindered by felt tensions and all the linear contraction values must have been correspondingly reduced, but this does not obscure the distinction between the successive phases.

Inter-communication between Fiber and Web

There now arises the critical question as to *how* the shrinkage of individual fibers is communicated partly or wholly, to the web which contains them. This question does not arise in the case of contraction due to inter-fiber contraction, where the forces of surface tension are themselves the link between the components. But in the case of intra-fiber contraction, it is a question of central importance, for the shrinkage forces within the component do not of themselves provide a link between components.

Consider the case of a web, made from unbeaten cellulose fibers, which normally exhibits during drying a linear contraction within the main plane, of 1 to 2%. This includes any contraction attributable to inter-fiber shrinkage.

It must be noted that most of the fibers lie parallel to the main surfaces of the web, and we are considering at this stage a web exhibiting random orientation of fibers within the main plane. Other factors being equal, the contraction might be expected to be divided equally between the *thickness* on the one hand, and the web *area* on the other hand. Thus, if the fiber diameter shrinks by 10% and the whole of this shrinkage is efficiently communicated to the web, we should expect the thickness to contract by 10% and the area by 10%. On the simplest view, this area contraction is equivalent to a linear contraction, within the main plane, of around 5%. The observed value of 1 to 2% seems to imply very inefficient communication between the component fibers even if it is all attributable to intra-fiber contraction. As an alternative explanation it could be suggested that lateral restraints to web contraction within the main plane may still further favor contraction in the thickness. Such preferential distribution of contraction would imply that the fibers dry in a distorted shape—so that a fiber of solid circular cross section would be pulled into an elliptical cross section with the long axis in the plane of the sheet. Such distortion could only take place if the forces preventing planar contraction could be so efficiently communicated as to subject the individual fiber to considerable lateral restraint. While such conditions can be visualized in the drying of MG paper, and in ordinary cylinder drying of a wet beaten paper, they seem unlikely to apply in the case of a free drying web of unbeaten stuff. The low level of tension developed during drying of such a sheet argues against this possibility [see Rance (*10*)]. It is more reasonable to argue that the low level of planar contraction of unbeaten webs is simply due to poor communication between the fiber component and the assemblage.

At the other extreme, we have the case of a web made from extremely beaten pulp. In this case, the total linear contraction in the main plane can approach 20% corresponding to an area contraction of around 36%. Since the density of the resultant paper approaches that of cellulose, and there are no significant air spaces, it is clear that the component shrinkage has been largely communicated to the assemblage, the web contracting as a coherent body.

Thus, it is evident that web contraction due to fiber shrinkage is closely dependent upon degree of beating, just as the contraction due to surface tension between fibers is dependent upon the degree of beating. The reasons for dependence are, however, not identical in the two cases, though closely allied. We have noted that beating assists surface tension contraction by increasing the surface over which that tension can operate, by decreasing the resistances to compaction of the assemblage, and by providing fiber-fiber bonds which can fix the contraction. In the case of web contraction due to fiber shrinkage, beating assists the transference of the shrinkage from fiber to assemblage first by providing (through earlier surface tension compaction) conditions of intimacy between the swollen fiber surfaces: and second, by providing fiber-fiber bonds which serve as the essential link enabling the shrinkage to be transmitted from each fiber to its neighbors and thence to the web. *Thus inter-fiber bonding is seen as the end point of inter-fiber web contraction, and as the starting point of intra-fiber web-contraction. This is central to the whole subject.*

These considerations show that the web contractions due to surface tension and fiber shrinkage are "sympathetically" linked through fiber/fiber bonding. A contraction due to fiber shrinkage by the transfer mechanism postulated above cannot normally occur without a corresponding prior contraction due to surface tension between fibers.

RELATION BETWEEN WEB SHRINKAGE AND PAPER EXPANSION

Figure 3 has shown that it is possible to distinguish directly between the contractions attributable to the two phases, during the actual drying of a web. In addition, Pritchard (*11*) has recently suggested that two types of contraction can be indirectly distinguished through the water expansion properties of the dried paper. As reported earlier by Rance (*10*), only a part of the web contraction manifests itself as a paper ex-

pansion on subsequent wetting. There is a linear relationship between the two quantities, such that between 40 and 60% of the web contraction is reversible on wetting the sheet, the proportion varying according to the type of pulp. Figure 4 shows the relationship for these different pulps.

Pritchard's theory is that the reversible part of the web contraction is attributable to intra-fiber shrinkage, while the irreversible part is that due to inter-fiber contraction. Stamm (*3*) has expressed similar, though more cautious, views. He clearly distinguishes, as we have done here, between the inter-fiber and intra-fiber components of web shrinkage but while stating explicitly that the intra-fiber component is quite reversible, he suggests that the inter-fiber component may be only *partly* irreversible. The case for the reversibility of the intra-fiber shrinkage is certainly strong. Ignoring hysteresis, and provided extreme dehydration involving deeper levels of molecular bonding is avoided, the shrinkage of a predried cellulose fiber is largely reversible on rewetting: these conditions apply here where we are considering shrinkages and expansions relating to a lower limiting water content of around 9%, with webs made from pulp already once predried. It seems to follow logically that web contraction caused by such fiber shrinkage should correspondingly be reversible. Certainly this must be the case with a dense sheet where the fiber expansion is necessarily transmitted *in toto* to the assemblage.

The case for the irreversibility of the inter-fiber web contraction is not so strong. Pritchard (*11*) has argued that rewetting of the web provides no force tending to separate the fibers, comparable to the surface tension which drew them together. This is certainly so with regard to that part of surface tension contraction which involved sliding together of unstrained fibers: but it is not necessarily so with regard to that part of the surface tension contraction which involved distortion of individual fibers for that distortion will provide some force of elastic recovery. What can safely be said, however, is that this reversal force will be operating, as far as planar expansion is concerned, against considerably greater restrictive forces than did the original surface tension, for the sheet has been considerably compacted in thickness by its first drying.

Taking all these factors into account, there is a qualitative case for expecting a major part of the planar surface tension contraction to be irreversible. On the other hand, one might expect a fair degree of reversibility of the surface tension contraction of the *thickness* of the web for there is no significant hindrance to re-expansion in that dimension. Any recovery force, however slight, can be readily translated into a thickness expansion. The difference in this respect between thickness and planar effects has been demonstrated by some simple tests on dense papers made from wet beaten stock. Thickness measurements were made on such paper before and after complete water soaking. A thickness expansion of about 70% was found. Intra-fiber expansion could only account for about 25% expansion even if it were all concentrated in the one dimension, so it is clear that much of the inter-fiber surface tension contraction is reversible, within the thickness of the sheet. Now another paper was tested, similar in every respect, except that it had been wet strengthened with an amino resin. The thickness expansion was found to be considerably reduced to about 35%. Evidently the addition of water-insoluble bonds had inhibited much of the reversibility of the inter-fiber contraction in the thickness. On the other hand, this wet strengthening had no significant effect on the planar water expansion of that paper, which was 2.7% for both treated and untreated paper. This well-known fact that resin bonding of the fibers has little effect on planar water expansion of paper is direct evidence that little of that expansion can be due to inter-fiber movement. Clearly, it must be largely due to intra-fiber movement which cannot be reduced by the provision of extra bonding between fibers.

Apart from secondary effects, there is thus a reasonable case for identifying the reversible portion of planar web contraction with the fiber shrinkage, and the irreversible portion with surface tension contraction. On this view, the difference in slope between the lines for the different pulps in Fig. 4 would be attributable to a difference in the ratios of the two types of contraction. This implies that for pulp A, a weak bleached sulphite, there is less fiber shrinkage contraction for a given amount of surface tension contraction, than in the case of pulp C, a strong bleached sulphate pulp.

This is consistent with the fact that the fibers of pulp A are more readily shortened than those of pulp C, whereas the fibers of pulp C are more readily bonded together than those of pulp A. These differences should favor inter-fiber contraction with pulp A, and contraction due to intra-fiber shrinkage with pulp C.

The First Anomaly

There are two anomalous features which fail to conform to this picture. The first anomaly, which has been noted elsewhere as posing an unsolved problem (*10*) lies in the fact that a web made from unbeated pulp exhibits a significant contraction during drying (usually 1 to 2%) and that this contraction is *entirely* reversible on rewetting [see Fig. 4 where the *real* origin of the curves is the point (2,2)]. On the view presented above, only that part of web contraction caused by fiber shrinkage is reversible, yet at the same time it has been argued that inter-fiber web contraction is a necessary preliminary to intra-fiber shrinkage.

It is clear that a third type of web contraction must be introduced, not merely to preserve the pattern of interpretation that has been presented, but also to explain how such a web made from intact fibers, incapable of fiber-fiber bonding, is capable of *any* contraction at all on drying. The very existence of such web contraction, as well as its total reversibility, seems inexplicable on the basis of the considerations given earlier. There is one aspect of fiber shrinkage mentioned earlier in passing, which may afford a clue to this apparent anomaly. When describing the volume and lateral shrinkages resultant on fiber desiecation, it was also noted that the "fibers attempt to coil and twist." This twisting can be readily demonstrated by suspending a fiber by one end, and attaching to the lower end a transverse bar of material, to provide in effect a miniature torsion balance. If a drop of water is brought near to the fiber, there is an instantaneous untwisting: the transverse bar rotates several times, the maximum ef-

fect being reached when the fiber is actually wetted. When the drop is withdrawn, retwisting occurs, and the bar spins back again. Bisset and Dadswell (*16*) also have described this effect in some detail, and have noted that it causes a pseudo-shortening of the fiber. Considerable forces must be deployed in such twisting of drying cellulose fibers, and it is suggested that these are the forces directly responsible for the planar contraction of webs of unbeaten pulp.

A planar contraction could only be caused by twisting of the constituent fibers if: (1) in the wet condition the fibers lie substantially parallel to the main plane of the sheet; (2) the fibers are long enough to entangle and thus lever upon one another; (3) there is no bonding between fibers at their points of contact for this would inhibit the twisting.

A possible concomitant of this type of planar contraction is a thickness expansion. In other words, there is not necessarily a genuine volume contraction, as with the other two types of web contraction.

Being based upon the reversible shrinkage of the individual fibers, this twisting contraction should be fully reversible as long as no inter-fiber bonds are formed. It could only appear in a completely unbeaten sheet, and should rapidly disappear as beating proceeds, to be replaced by inter-fiber and intra-fiber web contractions of the types already described, both of which depend for their development upon fiber-fiber bonds. Conclusive evidence to substantiate this hypothesis is difficult to obtain, but an elegant piece of confirmatory evidence is forthcoming from the shrinkage properties of webs made from alkali-treated sulphate pulp of the very high alpha-cellulose type. If this type of pulp is beaten in a Valley beater, it exhibits, like other pulps, a progressive increase in web contraction as beating proceeds. If, on the other hand, it is beaten in a Lampén mill, an extraordinary result is obtained: the web contraction at first *decreases* on beating, before the familiar increase sets in. This has been repeatedly confirmed in Lampén mill beatings in a steady succession of high alpha-cellulose pulps. Typical figures are shown in Table I.

Clearly this initial decrease in web contraction is quite inexplicable if the contraction of the unbeaten web is an aspect of a genuine volume contraction arising from the inter-fiber or intra-fiber contractions fixed into the web through fiber-fiber bonds. Beating can only increase those two effects through the various mechanisms discussed earlier.

If, on the other hand, the contraction of the unbeaten web is caused by the coiling effect postulated above, then fiber-shortening unaccompanied by bond formation could reduce the contraction. The shorter the fibers, the less the coiling leverage which serves to "concertina" the assemblage. High alpha-cellulose fibers, plus Lampén mill beating, give unique conditions for such shortening without promoting fiber-fiber bonding.

Table I. Shrinkage of Laboratory-Made Sheets of High Alpha-Cellulose Pulp Beaten in a Lampen Mill

	Lampen mill revolutions			
	0	*4000*	*8000*	*24,000*
Sheet density	0.46	0.58	0.62	0.68
Linear shrinkage, %	3.3	2.3	2.7	3.3
Drainage rate, °S.-R.	15	16	17	21

They do not readily bond together, being devoid o hemicelluloses, and under heavy beating pressure as i the Lampén mill, the fibers shorten without fibrillation Thus, the anomalous total reversibility of the contrac tion of a web made from unbeaten stock, plus the reduc tion of that contraction consequent upon slight beating combine to give consistent evidence of a third mecha nism for web contraction: but it must be emphasize that this mechanism is applicable only to the extrem conditions of unbeaten or very lightly beaten stock It must be rapidly inhibited by the appearance bondable surfaces in the beating of ordinary types pulp.

The Second Anomaly

The second anomaly is equally important. It ha been noted earlier that with efficient communication be tween web components, the maximum web contractio attributable to intra-fiber shrinkage should amount to 19% volume contraction, divided equally between thick ness and area (10% on each), where the web consist of fibers lying parallel to the main surfaces of the shee Thus, the shrinkage of one diameter of the fibers is allo cated wholly to web thickness shrinkage, while th shrinkage of the diameter at right angles is allocate to an *area* shrinkage, being spread over two dimen sions. For such a web the maximum linear contractio attributable to intra-fiber shrinkage should be aroun 5%, yet Pritchard's thesis, coupled with the values i Fig. 4, implies that the intra-fiber shrinkage can rise a high as 9% (calculated from 10% expansion value There are two possible explanations of this anomaly:

1. At high levels of beating, the distribution of th total intra-fiber volume shrinkage between web thick ness and web area may differ from the pattern deduce for a web composed entirely of fibers lying parallel the main plane.

2. The shrinkage and swelling of the fiber materi may increase on beating.

Consider the first of these possibilities. A high beaten stock contains a high proportion of fiber fra ments of indeterminate shape, and the average fib length is well below the thickness of the web and inde of the dried sheet (at 0.1 mm. it would be only thre times the diameter of the fibers). There are few in tact fibers left to lie parallel to the surface of the shee and it is possible that in such a sheet the distribution the intra-fiber contraction may ultimately approach condition of equality between the three dimensions, a opposed to the equality between thickness and area postulated for a web of unbeaten fibers. If the 19% volume shrinkage were equally divided betwee three dimensions, the linear shrinkage in each dimen sion would be 7%. This 7% is the *maximum* linea web contraction that could be attributable to a 19% volume intra-fiber shrinkage.

There still remains a difference of 2% between th value of 7% and the observed maximum of 9%. It always possible that the accepted mean value for wat sorption, based on Stamm (*3*) and Heath and Johnst (*7*), was an underestimate. To account for a 9% linear shrinkage, the sorption value for 65 to 100% R.H would need to be 21% instead of the accepted 15%. I on the other hand, we assume the reliability of th accepted value, there would appear to be some case f

the second of the above suggestions, that heavy beating may somewhat increase the water sorption in this context. Though a number of workers have reported that beating has a negligible effect on water vapor sorption, Seborg *et al.* (*6*) have reported a significant increase, which could raise the 65 to 100% R.H. sorption by 3%, and more recently Wijnman (*17*) has repeated a more appreciable increase in the water vapor sorption of heavily beaten cotton fibers. He found that 12 hr. of beating in a Jokro mill to a Schopper-Riegler wetness of 77°, increased the sorption at 75% R.H. and 25°C. from 8.7 to 10.8%. This is an increase of an order sufficient to account for the extra 2% linear water expansion of the sheets under discussion.

It is also appropriate to refer to the opinion expressed by Stamm (*3*), that "beating undoubtedly increases the water-binding power of a pulp appreciably between the fiber saturation point and complete saturation," i.e., between the equilibrium relative vapor pressures of 0.99 and 1. Lack of accurate knowledge of events at this zone of vapor pressure is an obstacle to a precise analysis in the present problem. It renders inprecise the determination of the total water sorbed by the fibers and still further clouds the situation when beating is involved. It is even possible that this "zone of obscurity" may constitute an overlap between web contraction caused by surface tension forces and that caused by intra-fiber shrinkage. If so, it may be permissible to attribute the extra 2% linear expansivity of wet beaten sheets with equal validity either to an increase in fiber sorption caused by beating, or to the supervention of a reversible component of inter-fiber web contraction at this level of beating. The two explanations may well be alternative valid descriptions of the same situation.

Evidence from Plasticizing Experiments

Further evidence can be presented to support the view that the water expansion of the dried sheet is the reverse aspect of contraction attributable to intra-fiber shrinkage. Kubat (*18*) has recorded that if paper is plasticized by soaking in a solution of plasticizer, followed by redrying, it is found to be increased in length (measurements being done before and after at a controlled relative humidity). He found the degree of mechanical softening to be related directly to this increase in length. Pritchard (*19*) has done similar but rather more extensive work and has included water expansion measurements on the treated paper. It was found that the increase in length caused by the softening treatment was accompanied by an equal reduction in water expansion. The results are summarized in Table II and Fig. 5. The main point to note, in the present context, is that the original value of 9% water expansion has been reduced to as low as 4% by urea, a nonhygroscopic softening agent. Now it is clear that such an agent achieves its effect by interfering with the hydrogen bonding between the cellulose units [cf. Fisher (*20*)] and thus by swelling the cellulose just as water swells it. On the other hand, urea is not an effective surface tension reducer and should therefore be incapable of affecting significantly any part of the expansion and contraction of the formed sheet that might be attributable to inter-fiber forces. Consequently the reduction of linear water expansion from 9 to 4% is direct evidence that a major part of this water expansion is related to intra-fiber swelling.

STRUCTURAL DISTORTIONS CAUSED BY WEB CONTRACTION

The question of identifying the reversible contraction with intra-fiber shrinkage has been heavily emphasized because of its importance regarding structural distortion. Following on the view established above, the inter-fiber planar compaction is not regarded as a major source of structural distortion. It is considered to cause uniform compaction with comparatively few residual local stresses. The intra-fiber planar compaction, on the other hand, is regarded as a major source of structural distortion, and consequently as the source of physical effects other than hygro-dimensional changes—the tenacity and extensibility being particularly affected.

It has been emphasized that planar web contraction attributable to intra-fiber shrinkage is essentially dependent upon the formation of bonds between fibers. It must now be emphasized that in a randomly oriented sheet this bond formation must simultaneously lead to a pattern of structural distortions and consequent local frozen-in stresses. This arises from the anisotropic nature of the cellulose fiber which swells and contracts diametrically but not along its axis. In a random aggregate the diametric shrinking of any one fiber will be opposed by the axial stability of the fibers lying across it. If there is no bonding between the fibers, then they can move relatively to one another during shrinking, without restraint but also without communicating their diametric contractions to the web. As soon as the surfaces begin to stick together, then a diametric contraction will cause a corresponding axial strain in the crossing fibers, and correspondingly it will manifest itself as a web contraction. The central point is that *the intra-fiber shrinkage can cause web contraction only through axial deformation in the crossing fibers.*

This deformation can be either a compressive or a bending strain. The pattern of deformation adopted by the fibers and the web will conform to a condition of minimum energy. In a porous structure as with a free-beaten sheet, this is likely to involve bending rather than compression. In a denser structure compression may supervene.

A convenient way of visualizing the situation is to consider one fiber X being subjected to strain by the

Table II. Water Expansion and Clark Rigidity Values on Plasticized Paper

Description of plasticizing solution	*Rigidity, L3/100*	*Change in length, %*	*Water expansion, %*	*Reduction in water expansion, %*
Blank	27	0	8.7	0
10% ethylene glycol	18	0.5	7.9	0.8
10% diacetin	16	1.0	7.5	1.2
10% triethanolamine	16	1.2	7.5	1.2
20% ethylene glycol	15	1.5	7.2	1.5
10% glycerol	14	1.5	7.0	1.7
7.5% urea	13	1.4	6.8	1.9
20% triethanolamine	12	2.2	6.5	2.2
20% diacetin	11	2.2	6.4	2.3
30% sodium salicylate	9	3.5	5.2	3.5
15% urea	9	2.5	6.0	2.7
30% glycerol	5	4.0	4.8	3.9
30% urea	2	4.5	3.8	4.9

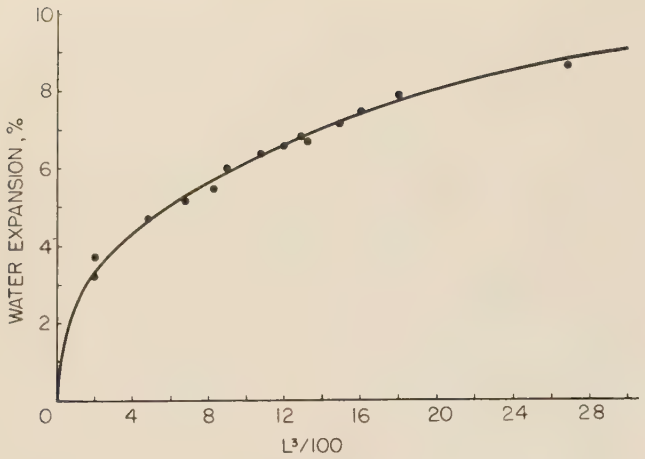

Fig. 5. Relation between stiffness and water expansion of plasticized paper

diametric shrinkages of the fibers, A, B, C, D, etc., crossing it. In order to cause a strain, the crossing fibers must be considered to be bonded together, and also be bonded to fiber X at two or more places. Under such conditions, X must bend as in Fig. 6b, when A, B, C, D, etc., shrink. Next consider the situation resulting from more exposure of bondable surface. Assume that fiber X now bonds at three or more places to the bridge of crossing fibers A, B, C, D, etc. Then the result must be as in Figs. 6c and 6d. Finally, consider a closely packed structure where the number of bonding points is greatly increased toward the condition where the whole surface area of fiber X is bonded to crossing fibers. The net result as in Fig. 6e would involve axial compression of X, or bending of the whole element as in Fig. 6f.

The whole web is made up of fibers crossing at all angles, and on an average every fiber is subjected to an axial strain equal to that part of the linear contraction of the web which is attributable to intra-fiber shrinkage. When the concentration of inter-fiber bonding is low or moderate, then the consequent bending of the strained fibers will result in what may be termed a micro-cockle (*not* micro-creping, because it is an *area* effect—not a linear effect). This can be visualized by considering a thin layer of fibers assembled in conventional manner as in Fig. 7. This depicts an assemblage of groups of fibers oriented at right angles to one another, and bonded at the boundaries of each group. When the fibers in group EA and EC shrink, they buckle the fibers in EB, thus forcing element EB into a cockle. Conversely, when the fibers in EB and GB shrink, they buckle the fibers in FB, and so on. This type of cockle in the thickness of the sheet can readily occur while the structure is loose enough for the laminae to act independently. As the bonding concentration increases, bending movement of the fiber may become increasingly restricted, though this is offset by the fact that simultaneously the fiber becomes more flexible and conformable to the developing structure.

When the sheet becomes highly compacted, its structure can perhaps be represented as in Fig. 8, in terms of superimposed laminae of opposite grain. With such a tight packing, diametric shrinkage of the fibers could be accommodated only through axial compression of the fibers in the transverse lamina. If there were no resistance to axial compression, then the composite structure would shrink in each planar direction by 10%, in area by 19%, and in volume by about 28%, as compared with the 20% volume shrinkage of the individual fiber. In other words, there would be a volume compression as well as a volume shrinkage.

Table III. Extensibility and Intra-Fiber Web-Contraction Values for Laboratory-Made Sheets (Stuff Beaten in Valley Beater)

Freeness, °S.-R.	*Apparent sheet density*	*Average fiber-length, mm*	*X Extensibility, %*	*Y Intra-fiber web contraction, %*	*X − Y, %*
		Pulp M			
13	0.48	1.72	2.5	2.6	0
17	0.65	1.10	6.2	3.0	3.2
27	0.72	0.84	7.5	3.3	4.2
42	0.79	0.65	8.0	3.6	4.4
56	0.84	...	10.0	4.3	5.7
68	0.87	0.42	11.2	4.8	6.4
84	0.98	...	15.0	7.8	7.2
		Pulp M[1]			
13	0.47	1.72	2.5	2.6	0
18	0.64	1.04	5.6	3.0	2.6
37	0.73	0.70	7.5	3.6	3.9
53	0.83	0.50	8.5	4.2	4.3
72	0.89	0.30	10.1	6.2	3.9
81	0.93	...	9.0	7.8	1.2
88	1.00	...	8.7	9.0	0
		Pulp N			
14.5	0.49	1.60	4.2	2.0	2.2
21	0.63	...	6.4	2.8	3.6
22	0.71	1.25	7.5	3.4	4.1
32	0.75	1.08	9.2	3.8	5.4
52	0.81	0.90	12.5	5.6	6.9
73	0.88	0.80	17.0	7.7	9.3
87	0.92	...	20.0	8.6	11.4

In fact, the force deployed by diametric shrinkage will be balanced against the resistance to axial compression, and an intermediate condition will be reached. If we assume an intrinsic symmetry whereby the compressive axial elasticity is equal to the tensile diametric elasticity, then the net result should be a linear shrinkage of 5% in each planar direction.

Any actual case of web contraction due to intra-fiber shrinkage can be viewed as a combination of the conventional cases depicted in Figs. 7 and 8. In either case a 10% diametric shrinkage leads to a 5% strain in each planar direction. Whether the case depicted in Fig. 8 enters appreciably in practice, is a moot point. It is possible that even with tightly bonded sheets, the strain

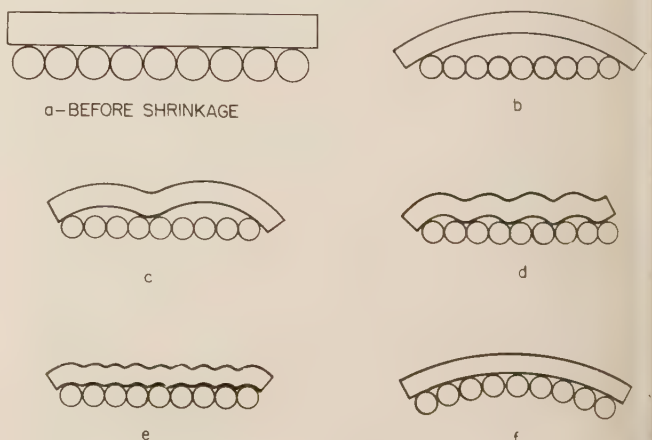

Fig. 6. Distortions caused by diametric shrinkage of fibers

Table IV. Extensibility Values for Laboratory-Made Sheets Dried With and Without Restraint (Stuff Beaten in Lampen Mill)

Freeness, °S.-R.	Apparent sheet density	Extensibility, % Dried under restraint C	Extensibility, % Dried without restraint D	D − C, %	Intra-fiber web contraction, %
13	0.6	1.4	2.3	0.9	1.3
22	0.74	2.8	5.5	2.7	2.1
50	0.82	3.3	9.6	6.3	4.6
62	0.89	4.5	12.1	7.6	5.8
80	1.17	4.1	16.1	12.0	9.0

in each layer is accommodated by flexion rather than compression, so that the final material can be visualized as a composite structure of "nested" cockled layers, each formed on the pattern of Fig. 7.

RELATIONSHIP BETWEEN WATER EXPANSION AND EXTENSIBILITY

In all the cases visualized, there is a pattern of local distortions in the dried web, equivalent in aggregate to that part of the linear shrinkage of the web which occurred after bond formation. These distortions are liable to manifest themselves if the paper is subjected to tension, and this is the direct link between the hygroscopic and mechanical properties of the sheet.

Earlier publications by the writer (*21*) have stressed the technological interest in the relations between these properties. At the same time, it is necessary to avoid the danger of assuming a closer quantitative correspondence than may actually exist. Consider the extensibility of a sheet of paper dried without restraint to area contraction. If fiber X in Fig. 6 is axially loaded, then it may be expected to straighten with simultaneous rupture of one or more of the bonds which have allowed the diametric shrinkage of A, B, C, D, etc. to buckle or bend X. This is a reasonable explanation for the frequently observed fact that contraction of a drying web considerably increases the extensibility of the dry paper (see Steenberg (*22*), Rance (*23*)).

On this view, we might in general expect to find in a sheet of paper an extensibility component related to the intra-fiber contraction of the web, though the extension would necessarily involve the rupture of some of the inter-fiber bonds to permit the crumpled fibers to straighten. Comparison of the extensibility of free-dried sheets with the intra-fiber shrinkages does indeed

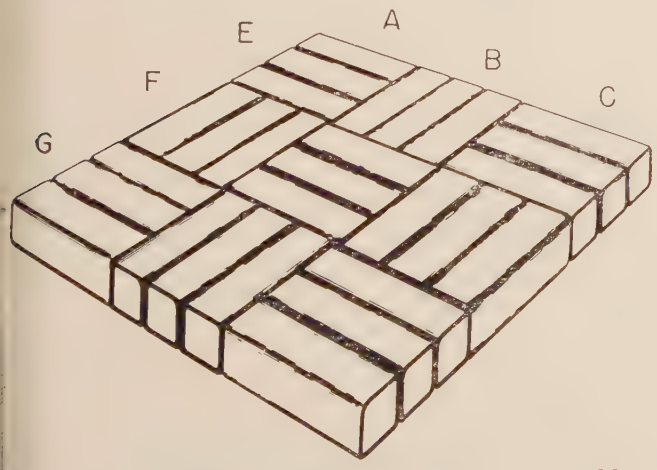

Fig. 7. Conventional representation of fiber assemblage

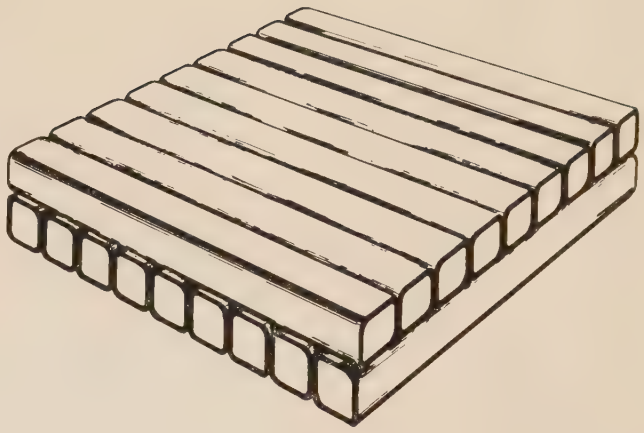

Fig. 8. Conventional representation of densely packed laminae

show a certain correspondence. In Table III some appropriate data from Glover, Pritchard, and Ray (*24*) have been assembled for sheets made from different pulps beaten to different degrees in different ways. Values are given for extensibility, post-bonding web contraction due to intra-fiber shrinkage, and the difference between the two. Also the average fiber lengths of the stock are shown.

These values show that, in general, beating increases the extensibility (X) of the paper, just as it increases the web contraction due to intra-fiber shrinkage (Y). At the same time, X is, in general, greater than Y, to a degree which increases with beating. In no case is X less than Y. It is suggested that X is compounded of two components—one directly caused by and related to Y, the other relating to intrinsic mechanical properties of the assemblage.

This view is supported by test values for the extensibility of some other sheets, dried with and without restraint, as shown in Table IV.

The values for the uncontracted sheets clearly confirm that there is an intrinsic extensibility component, quite independent of web contraction, but similarly subject to increase on beating. The differences between extensibilities of restrained and unrestrained sheets are seen to conform with the general trends of the values for web contraction due to intra-fiber shrinkage, but are somewhat greater (see columns 5 and 6 in Table IV). It is not unreasonable to suggest that there may be a second order interaction between the intrinsic extensibility of the web, and the shrinkage extensibility, to account for this third extensibility component.

A note of warning must be sounded here regarding the weight that can be attached to extensibility values. Elsewhere the writer has emphasized the dependence of mechanical test values upon the testing conditions—especially upon the sample dimension. Recorded stretch values for a heterogeneous material are only indirect indications of extensibility, and therefore no precise fundamental significance should be attached to numerical magnitudes: but this does not invalidate the significance of trends.

It is not appropriate here to inquire further into the nature of the intrinsic component of the extensibility of paper. It is enough to note that we have clear evidence for the existence of a shrinkage component which manifests itself through rupture of inter-fiber bonds,

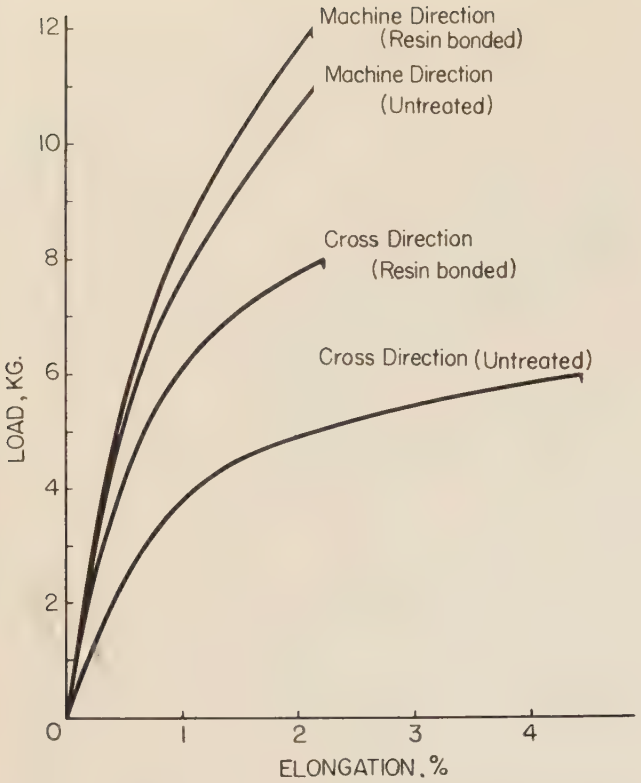

Fig. 9. Load-elongation curves for resin-bonded paper

with consequent straightening of crumpled fibers lying in the direction of loading.

Bond Reinforcement

By strong reinforcement of the fiber/fiber bonds it is possible to eliminate this shrinkage component of the extensibility, without necessarily eliminating the water expansivity of the paper. This has been demonstrated in some work involving the treatment of a fairly free-beaten paper with solutions of amino-resins. The paper was machine made, and consequently the machine-direction shrinkage had been inhibited by machine tension, causing anisotropy in both water expansivity and tensile extensibility. After resin treatment the anisotropy ratio for water expansitivity remained unchanged at about 3 (CD:MD). On the other hand, the tenacity anisotropy was reduced, while the stretch anisotropy was completely eliminated, as shown in the load/elongation curves in Fig. 9. Evidently the shrinkage-component of the cross-direction extensibility had been completely eliminated by bond reinforcement which prevented the piecemeal rupture of bonds and straightening of crumpled fibers.

EFFECT OF DRYING TENSION ON WATER EXPANSION

The observations in the last paragraph serve to introduce the technologically important subject of machine tensions on the paper web, during the evaporation of water. Although the considerations so far presented have largely dealt with tests on laboratory made sheets, they contain the principles needed for an understanding of events on the paper machine.

The cross direction of machine-made paper generally involves a substantial degree of freedom to contract during drying, whereas the machine direction involves considerable restraint, with the expansivity and tensile extensibility, and increases tenacity.

Considering, first, water expansivity, it is evident that this might be reduced in three ways: (1) by reduction of the shrinkage and conversely of the expansion of the individual fiber, (2) by diametric extension of the fiber in the direction of loading, (3) by reduction of the efficiency of communication during shrinkage, and during expansion, between the fiber and the web. Considering (1) it is not reasonable to postulate that the volume shrinkage of the individual fiber can be eliminated by applied tensile force, though it is possible that in dense papers an applied tension might force fibers to shrink preferentially in the diameter at right angles to the tension. Thus, a fiber of circular cross section might be forced to dry down to an elliptical cross section. On rewetting the deformed fiber would tend to revert to original shape and consequently would exhibit reduced expansion in the direction of tension.

In free-beaten papers it seems unlikely that either mechanism (1) or (2) could apply, and more likely that the tension reduces bonding between adjacent transverse fibers (3). On this view, these fibers are forcibly held apart, while correspondingly the fibers lying in the direction of tension are prevented from bending and crimping under the influence of the transverse shrinking fibers. On rewetting such a sheet should exhibit reduced water expansion in the direction of tension, owing to the reduced communication between the fibers that have been forcibly held apart.

There is evidence that mechanism (3) applies to some extent even in the restraint of webs made from wet beaten stuff. In the course of work on paper machines making very dense, near transparent papers from very wet beaten stock, it has been noted that samples removed from the web and allowed to dry without planar restraint, are more transparent than machine-dried paper. Similarly, the edge areas of the machine-dried paper, which have virtually complete freedom to shrink in the cross direction, are sometimes more transparent than areas toward the middle of the web. Thus, it seems that even with dense sheets, the machine tension can forcibly prevent bonding between some of the transverse fibers, thus creating interfaces which reflect light and cause opacity.

Shrinkage Recovery

It should be noted that in each case, drying of the re-

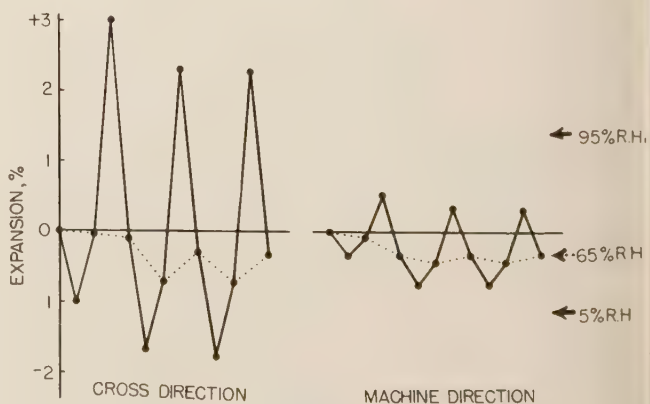

Fig. 10. Dimensional changes in paper caused by humidity cycling

wetted sheet might be expected to undo some part of the effect of the original tension. Any fibers with deformed cross section should revert in part at least to the shape they would have assumed in the absence of that tension, and fibers forcibly kept apart by that tension should be liable to revert to a condition of bonding approaching that which they would have assumed in the absence of tension. This is because on redrying, shrinkage forces are operative which were not able to act when the sheet was first dried, under tension.

Such reversion is in fact one of the most striking hygroscopic characteristics of paper dried under restraint. As recorded by Larocque (*2*), Smith (*23*), and Rance (*10*), a significant proportion of tension-inhibited shrinkage is always recoverable on rewetting and redrying. Consequently, the tension direction of machine-made paper always exhibits a significant hygroinstability as determined by the change in dimension after a wetting/drying cycle, even though it exhibits a very low expansivity on wetting. Figure 10 shows the dimensional changes consequent upon humidity cycling of machine-direction and cross-direction strips of a dense, wet beaten paper. The broken lines are humidity isometers.

The diagrams show that the cross-direction strip also can exhibit a net recovery after a humidity cycle. This recovery was actually greater, in absolute amount—than the recovery of the machine direction strip, though much smaller if expressed as a proportion of the initial expansion on wetting. The cross-direction strip depicted in Fig. 10 was actually cut from a position about 1 ft. from the edge of the web, and on this machine the design was conducive to a fair degree of restraint even in the cross direction, except at the very edges of the web. When cross-direction strips were tested at various positions across the sheet, including some at the outermost inch, it was found that a humidity cycle caused a net cross-direction shrinkage recovery over the whole sheet excepting about 2 in. on each of the edges. Samples from these edge areas, where there was complete freedom to shrink, failed to revert even to their original dimension after a humidity cycle. The test values for recovery over the 12 in. inwards from the web edge are summarized in Fig. 11. Machine direction values for dimensional change after cycling are included, and are seen to be independent of sample location. Figure 12 shows the initial total dimensional changes (95 to 5%) for both machine and cross directions. These data illustrate the technological

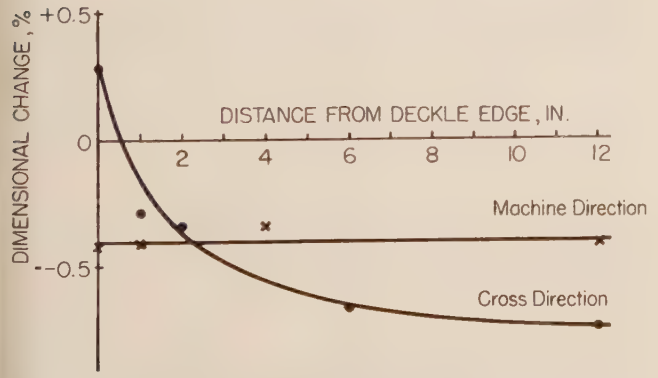

Fig. 11. Dimensional change at 65% R.H. after three complete cycles (dependence on sample location)

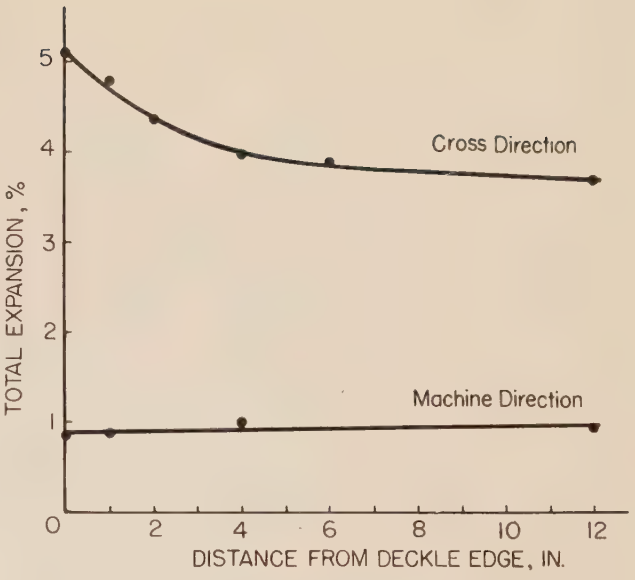

Fig. 12. Total expansion from 5 to 65% R.H. (average for three cycles) (dependence on sample location)

complexities and irregularities that can arise from structural changes during the water evaporation phase.

Tongren (*26*) has recently drawn attention to an additional factor which affects the pattern moisture expansivity of machine-made paper. He records figures for variation in cross-direction expansion (between 50 and 93% R.H.) which confirm the trends indicated in Fig. 12, in that the cross-direction expansion at the web edge was much higher than that at the web middle (1.3 against 0.7%). At the same time he also records figures showing the corresponding cross-direction contractions (between 50 and 5% R.H.), and in this case there is virtually no difference between edge and middle, both values being around 0.7%. A similar trend has many times been observed in our work. For example, the original values on which Fig. 10 was based showed a cross-web range from 4.1 to 2.6% for 65 to 95% cross-direction expansion, whereas the 65 to 5% cross-direction contraction values covered the much narrower range of 1.1 to 0.9%.

This leveling down of the variations in dimensional change can also be observed by comparing machine and cross-direction values illustrated in Fig. 10. The ratio of cross-direction:machine-direction expansions (65 to 95% R.H. first cycle) is around 8:1, whereas the ratio cross-direction:machine-direction contractions (65 to 5% R.H. first cycle) is around 3:1. The explanation is very simple. The apparent leveling down of differences is due to the fact that drying in the machine normally terminates at a water content equivalent to around 40 to 50% R.H. Consequently, *the paper has never been subjected to differential tensions at lower water contents.* The first drying down from, say, 40 to 5% R.H. takes place without restraints to shrinkage, and should therefore be substantially uniform over the sheet. On subsequent rewetting, provided the structural changes follow, in reverse, identically the same path as on drying, then expansion from 5 to 40% R.H. should also be uniform. Over this range of 40 to 5 to 40% there is no reason to expect either tension-induced anisotropy or cross-web variations for there have been no restraints applied to produce such effects. Re-

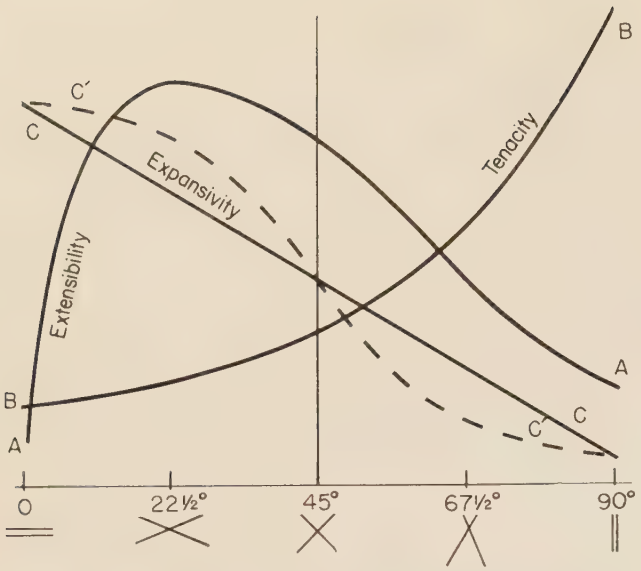

Fig. 13. Estimated trends of sheet properties with varying degrees of orientation

straint-induced effects should be largely confined to the region over which restraint was originally applied. On this view, a sheet of paper "remembers" and recapitulates the sequence of its past history. This is a principle of considerable importance and it may provide a useful tool for investigation of machine processes.

EFFECT OF DRYING TENSIONS ON TENACITY

The effect of tension during drying upon extensibility is self evident after the previous discussions. The effect on tenacity is not quite so obvious. As frequently recorded, the normal effect, provided excessive and damaging tensions are avoided, is a marked increase in tenacity. Table V gives the tenacities for sheets made from stock beaten to different degrees, and dried both with and without restraint. The tenacity increase is considerable for both dense and bulky (free beaten) sheets. Furthermore, the tenacity of sheets dried without restraint reaches a peak at around 60° S.-R., and falls off considerably at higher wetnesses. Restraint during drying not only increases the values over the whole range—it also inhibits this falling off in tenacity at high wetnesses, thus showing that this falling off is due to the increased web shrinkage at those levels. Such positive and substantial effects cannot be explained in negative terms as were the reductions in water expansion and tensile extensibilities. They must be explained in terms of a new pattern of bond formation, consequent upon the presence of tension during drying. We have seen that tensile stretch of a freely contracted sheet has to break bonds between transverse fibers before the tension can straighten the fibers lying in the direction of tension. On that view, the bonds which constitute the strength of the paper sheet are broken in piecemeal fashion. The maximum tenacity of a sheet must be largely determined by the number of bonds over which the load can be simultaneously distributed. If the bonds can be broken piecemeal, a low tenacity results, even though the consequent straightening of elements between successive ruptures can give a high extensibility. If tension is applied during drying, we have seen that the crumpling of fibers in the line of tension is inhibited. As for the fibers lying transverse to the line of tension, they are either kept apart (in free beaten papers) or their cross sections are distorted into elliptical shape. In either case a much tighter pattern of bonds in the machine direction must result.

It can be added that on the same view, a tension should increase the transverse contraction of the web, adding an extra mechanical crumpling to the fibers already crumpled up by the diametric shrinking of the fibers lying in the tension direction. Hence the increased cross-direction extensibility and reduced cross-direction tenacity caused by machine-direction tension, which has been frequently reported.

EFFECTS OF FIBER ORIENTATION ON WEB CONTRACTION

Preferential orientation of fibers in the machine or cross direction can drastically affect the planar anisotropies of the sheet and can seriously modify the end-effects of the processes discussed above. It leads to distinctive combinations of the hygroscopic and mechanical characteristics, and the resultant anisotropies are readily distinguishable from the anisotropies due to tension during drying. This can be understood from consideration of the extreme case of a web composed entirely of fibers lined up in one direction in the main plane.

During the phase of inter-fiber contraction of such a web, the orientation will promote dense packing of the fibers under the influence of surface tension. During the subsequent phase of intra-fiber shrinkage, web contraction will be almost entirely confined to the transverse direction. On rewetting the resultant sheet, a very high anisotropy of planar water expansion should result, equivalent in all respects to the swelling anisotropy of the fibers themselves [at least 10:1—see Weidner (*9*), and perhaps as high as 20:1—see Stamm (*3*)]. The tenacity anisotropy should be of the same order as that of the fiber. Tenacity anisotropy ratios for fibers are difficult to measure, but Frey-Wyssling (*27*) has deduced a value of 6:1 for cotton hairs, using data recorded by Berkley and Woodyard (*28*). The anisotropy of extensibility is of especial interest, for a completely oriented structure *gives no shrinkage-extensibility component*, since there are no transverse fibers to be crumpled by the shrinking diameters. Extensibility might therefore be expected to exhibit an anisotropy *in the same direction* as the predicted tenacity anisotropy.

If these considerations are carried to machine-made paper, where preferential fiber orientation is normally

Table V. Tenacities of Laboratory-Made Sheets (Strong Unbleached Sulphate) Made With and Without Restraint (Stuff Beaten in Lampén Mill)

Freeness, °S.-R.	*Apparent sheet density*	*Tenacity (breaking length), m. Dried under restraint*	*Dried without restraint*	*Web-contraction total, %*
16	0.65	5300	3150	1.3
17	0.72	7800	5850	2.3
20	0.75	8600	6250	3.3
26	0.80	9500	6700	4.7
60	0.86	9500	5600	10.7
70	0.87	9350	5600	12.0

in the machine direction, we may conclude that complete orientation should lead to a high M:C tenacity ratio, a high M:C extensibility anisotropy, and a very high C:M water expansion ratio. These predictions have been confirmed in the test values on such a machine-made sheet—a highly oriented condenser tissue paper made from rags—shown in Table VI. Note that the high M:C extensibility anisotropy is the feature which clearly distinguishes this type of orientation from tension-induced structural orientation, which gives a high C:M extensibility anisotropy. Also note that the M:C tenacity ratio is close to Frey-Wyssling's value of 6:1 for cotton hair.

Partial Orientation

The effect of fiber orientation of an intermediate degree, is a matter requiring experimental and theoretical study, for there are some unexpected complications. tions. Thus, starting at 90° orientation (see Fig. 13) tensile extensibility might be expected to have a rather low value which increases with decreasing orientation, through an increase in the shrinkage component of extensibility. On the other hand, at very low degrees of orientation, this transverse shrinkage component must be reduced toward zero as the number of fibers in the direction of tension is decreased toward zero. Probably, therefore, there is an intermediate degree of orientation which gives maximum transverse extensibility of the freely shrunken sheet, as indicated in curve A in Fig. 13.

Tenacity might be expected always to benefit from orientation in the line of tension, and here again Frey-Wyssling's interpretation of Berkley and Woodyard's work on fibers (reproduced in Fig. 14) gives general indications of what might be expected. An increase in fiber spiral angle from 45 to 90° was shown by Frey-Wyssling to correspond to an increase in fiber tenacity from 35 kg. per mm. sq. to around 110 kg. per sq. mm. Conversely, a decrease in angle from 45 to 0° was shown by extrapolation to reduce tenacity to a value around 18 kg. per sq. mm. Curve B in Fig. 13 has been drawn to conform to a similar trend.

Finally, transverse water expansion may be expected to increase continuously with increase in degree of orientation. A maximum, equivalent to the diameter swelling of the fibers, should be obtained at 0; a minimum, equivalent to the length swelling, at 90, and an arithmetic mean at random condition. In the absence of any contra-indication, a linear relation could be suggested over the whole range of orientation, giving curve C in Fig. 13, though a cubic equation type of curve could be drawn with equal validity, to satisfy the same points for 0, 45, and 90° (e.g., curve C). Experimental evidence to test C or C[1] is scanty. Newman's data, briefly recorded earlier by the writer (*10*) covered an orientation range from 42 to 24°. The correlation level of the results was poor, and the most that could be deduced was that on changing the orientation from 42 to 24° the moisture expansivity increased by a factor approaching 2. Curve C would imply an expansivity increase factor over this range of barely $1^1/_2$, so Newman's findings tend to favor C[1], which would give an increase factor between $1^1/_2$ and 2.

Table VI. Anisotropy Ratios for Paper Exhibiting Extreme Fiber Orientation

	Machine direction M	*Cross direction C*	*Anisotropy*
Tenacity, lb/$^3/_8$-in. strip	8	1.5	5.3:1 M:C
Extensibility, %	1.8	0.75	2.4:1 M:C
Expansivity, %	0.45	9.7	22:1 C:M

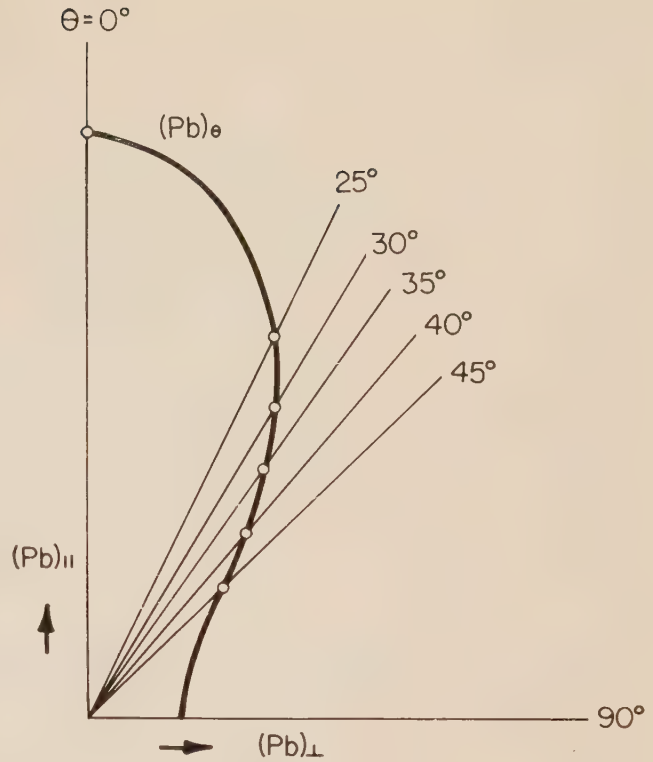

Fig. 14. Tensile strength Pb (kg./mm.²) of cotton hairs with different spiral angle θ (in polar coordinates); (Pb)∥, (Pb)⊥ tensile strength parallel and perpendicular to the microfibrils (reproduced from Frey-Wyssling (27))

Clearly there is need for more precise researches to test these speculations and to establish reliably the real trends of these various physical properties. The subject is one of considerable technological importance, and it is unfortunate that there are so many gaps in our factual information about it. The same conclusion applies strongly to the whole of this paper and the subject with which it deals. The writer is acutely conscious of the many and serious deficiencies in the data on which he has drawn, and especially regrets the lack of more extensive data concerning the shrinkage and expansion of the thickness and volume of paper. Reliable measurements of these dimensions are difficult to obtain, but when available they may serve to clarify some of the obscurities that have been indicated.

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Elastic Theory of Nip Stresses and Hysteresis Effect

HOMER E. MALMSTROM and J. P. NASH

This paper is concerned with the heat in supercalenders and the mechanism by which it is produced. The work was initiated when the need arose for selecting a size of motor to operate a new supercalender which was different in roll size and arrangement from anything used before. Neglecting lesser variables such as bearing friction, windage losses, and differences in ingoing and outgoing sheet tension, the principal factors which affect the power used are (1) speed of roll travel, (2) length of roll face, (3) applied load, (4) roll diameters, and (5) roll arrangement. It is reasonable to expect that the power required will be directly proportional to speed and to length of roll face. Measurements on other supercalender stacks show that motor power varies approximately as the three-halves power of the total nip loading. The effects of roll diameter and roll arrangement are not as easily seen and they are determined by a theoretical study of roll deformation in the nip. It is this deformation which requires most of the motor power and produces all the heat. The relationship which is developed for energy loss in a supercalender roll shows the anticipated relationships for speed, length, and loading, but also depends on a diameter function, the hysteresis constant, and a function of Young's modulus. Details, necessary mathematical relationships, and results were presented for the experimental determination of the hysteresis constant and the elastic modulus. The experimental values were used in equations giving horsepower requirements for fiber-filled rolls and steel rolls in supercalender stacks. Temperature distribution in fiber-filled calender rolls was discussed. The conclusion was reached that burnouts and charring can be expected to occur somewhere between the surface and 0.6 in. below the surface depending upon the rate of heat production.

It is well known to everybody having even the slightest acquaintance with a book paper mill that supercalenders run hot—so hot, in fact, that the fiber-filled rolls in the supercalender stack are sometimes destroyed by the heat. It is with this heat and the mechanism by which it is produced that the present paper is primarily concerned. The study began several years ago when the new Kimberly-Clark paper mill at Niagara, Wis., was in the design stage and there was a need for determining what motor size would be required to operate a new supercalender which was different in roll size and arrangement from anything used before. It is not difficult to list the principal factors which affect the power used, neglecting such lesser things as bearing friction, windage losses, and differences in ingoing and outgoing sheet tension. The principal factors are: (1) speed of roll travel, (2) length of roll face, (3) applied load, (4) roll diameters, and (5) roll arrangement. It can reasonably be expected that the power required will be directly proportional to speed and to length of roll face. Measurement on other supercalender stacks show that motor power varies approximately as the three-halves power of the total nip loading. But the effects of roll diameter and roll arrangement cannot easily be seen. These have been determined by a theoretical study of roll deformation in the nip. It is this deformation which requires most of the motor power and produces all of the heat.

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ENERGY LOSS IN A STRESSED BODY

In Fig. 1 there is plotted a typical stress-strain curve for a material that does not follow Hooke's law of perfect elasticity. The upper curve is the loading curve and the lower one the unloading curve. The area under the upper curve represents the work done in stressing the specimen under test. The area under the lower curve represents the work recovered in the unloading part of the cycle. The difference between these two areas, i.e., the area of the closed loop—represents the

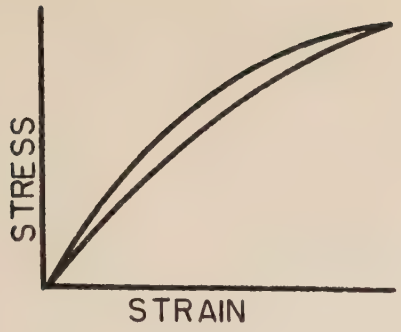


Fig. 1. Stress-strain relation

work lost through hysteresis. Since this amount of energy is lost from the loading mechanism it must remain in the specimen under test, and since the specimen ends up in its initial elastic state this difference must appear as heat energy.

In a supercalender roll each element of volume goes through such a loading and unloading cycle each time it passes under the nip. When a newly filled roll is put in the stack and started up, the stress-strain curve will not close on itself—there will be a small amount of permanent deformation in compression. This procedure cannot continue indefinitely or we would end up with no roll, and of course this does not happen. So after the new roll has been run for a day or a week, the curve will gradually become a closed one as shown in Fig. 1.

When equilibrium has been reached in the loading-unloading curves, it is reasonable to assume (*1*) that the amount of energy lost in each cycle will increase with higher loading. At this point let us assume that the amount of energy lost will be proportional to the amount of energy supplied in the loading cycle and see what conclusions are obtained.

We shall assume that the roll filling material of the fiber-filled roll of a supercalender stack is isotropic—i.e., the elastic properties are the same in all directions. This assumption, although not strictly true, must be made in order to proceed. In the computations of stresses in the vicinity of the nip we shall also assume that the material is perfectly elastic—i.e., it follows Hooke's law. With these two assumptions it is possible to say that the energy put into unit volume of the material during a loading cycle will be the strain energy, V_0, of unit volume at a point given by the following relation (*2*)

$$V_0 = \frac{1}{2E}(\sigma_x^2 + \sigma_y^2 + \sigma_z^2) - \frac{\nu}{E}(\sigma_x\sigma_y + \sigma_x\sigma_z + \sigma_y\sigma_z) + \frac{1}{2G}(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2) \quad (1)$$

in which V_0 is the strain energy of unit volume at a given point, E is modulus of elasticity in tension (Young's modulus), ν is Poisson's ratio, G is modulus of elasticity in shear, the σ's are normal stresses, and the τ's are shearing stresses at the point. The total strain energy for a stressed body is then given by

$$\int V_0\, dx\, dy\, dz \quad (1')$$

where units of V_0 are energy per unit volume (e.g., inch-pounds per cubic inch) with dimensions $ML^{-1}T^{-2}$.

The original assumption as to the amount of energy lost per unit volume per cycle can be stated as follows

$$\frac{dL}{dv} = HV_0 \quad (2)$$

where dL/dv is energy loss per unit volume at the point being considered and H is a dimensionless numeric giving the proportion of energy lost in one cycle of stressing.

If we integrate equation (2) over the entire volume of the body, we obtain the total energy loss per cycle:

$$L = H \int_v V_0\, dv \quad (2')$$

ENERGY LOSS IN A SUPERCALENDER ROLL

Let us now consider the particular case of a fiber-filled supercalender roll which is being stressed by a steel roll, as shown in Fig. 2. As the fiber-filled roll makes one revolution each volume element $r\, dr\, d\theta$ will go through one complete cycle of stress. The stress is a maximum while the element is on the z-axis above the roll center (i.e., in the nip) and is a minimum while the element is opposite the nip. It can be shown that this minimum is so small that we introduce little error by calling it zero.

The energy lost in the volume element through hysteresis during one revolution is

$$dL = HV_0\, r\, dr\, d\theta$$

Thus, with θ varing from O to 2π and r varying from O to R_1, the radius of the fiber-filled roll, we have

$$L = H \int_0^{R_1} V_0 2\pi r\, dr \quad (3)$$

where L is now the energy loss in unit length of roll per revolution and V_0 is the strain energy at radius r.

In any real fiber-filled supercalender roll there is a large steel shaft through the center, and the integration of equation (3) should be carried out with r varying from the radius of the shaft to that of the roll. But the stresses are entirely local and there is a negligible error in integrating from the center to R_1.

When V_0 from equation (1) is substituted into equation (3), we have an expression which gives energy loss in terms of stresses expressed as functions of r. To evaluate the resulting integral we use the relations (*3*) of equations (4) which give stresses as functions of z on the positive z-axis (see Fig. 2).

$$\left.\begin{aligned} \sigma_x &= -\frac{4\nu P'}{b^2\pi}\left(\sqrt{b^2+z^2} - z\right) \\ \sigma_y &= -\frac{2P'}{\pi b^2}\frac{(\sqrt{b^2+z^2} - z)^2}{\sqrt{b^2+z^2}} \\ \sigma_z &= -\frac{2P'}{\pi}\frac{1}{\sqrt{b^2+z^2}} \\ \tau_{xy} &= \tau_{xz} = \tau_{yz} = 0 \end{aligned}\right\} \quad (4)$$

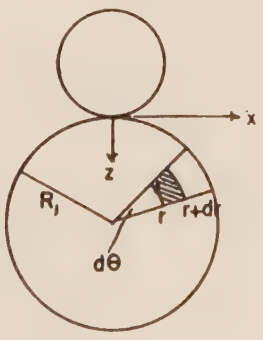


Fig. 2. Supercalender roll

In these equations P' is the force between the rolls per inch of face, b is the half width of the nip, ν is Poisson's ratio, and z is the distance from the nip center to the point under consideration on the z-axis. When equations (4) are substituted into equation (1) and then into equation (3) with the change in variable $r = R_1 - z$ (see Fig. 2), we have

$$L = L_{xx} + L_{yy} + L_{zz} + L_{xy} + L_{xz} + L_{yz} \qquad (5)$$

where

$$\left.\begin{aligned} L_{xx} &= \frac{4\nu^2 c}{b^4}\int_0^{R_1} f^2(R_1 - z)\,dz \\ L_{yy} &= \frac{c}{b^4}\int_0^{R_1} \frac{f^4(R_1 - z)}{b^2 + z^2}\,dz \\ L_{zz} &= c\int_0^{R_1} \frac{R_1 - z}{b^2 + z^2}\,dz \\ L_{xy} &= -\frac{4\nu^2 c}{b^4}\int_0^{R_1} \frac{f^3(R_1 - z)}{\sqrt{b^2 + z^2}}\,dz \\ L_{xz} &= -\frac{4\nu^2 c}{b^2}\int_0^{R_1} \frac{f(R_1 - z)}{\sqrt{b^2 + z^2}}\,dz \\ L_{yz} &= -\frac{2\nu c}{b^2}\int_0^{R_1} \frac{f^2(R_1 - z)}{b^2 + z^2}\,dz \end{aligned}\right\} \qquad (6)$$

in which $c = 4HP'^2/\pi E$ and $f = \sqrt{b^2 + z^2} - z$.

These definite integrals can be evaluated in a straight forward manner, and when the results are substituted into equation (5) we have

$$L = \frac{4HP'^2}{\pi E}\Big\{(2 + 2\nu)R_0 \tan^{-1} R_0 + (1 + \nu)^2 \ln (R_0 + \sqrt{1 + R_0^2}) - (1 + \nu)\ln(1 + R_0^2) + \frac{\sqrt{1 + R_0^2}}{3}(R_0 - 2R_0^3 + 2R_0^3\nu^2 + 5R_0\nu^2 + 6R_0\nu) + \frac{2R_0^4}{3}(1 - \nu^2) - 2R_0^2\nu(1 + \nu) - \frac{4R_0}{3}(2\nu^2 + 3\nu + 1)\Big\} \qquad (7)$$

where $R_0 = R_1/b$, i.e., the radius of the roll measured in units of half widths of the nip.

We know that R_0 will be a relatively large number, nearly always lying between 40 and 100, so that equation (7) can be simplified by using the following expressions and dropping terms involving $1/R_0$ and its higher powers:

$$\tan^{-1} R_0 = \pi/2 - 1/R_0 + {}^1/_3R_0^3 - \ldots$$

$$\sqrt{1 + R_0^2} = R_0 + {}^1/_2R_0 - {}^1/_8R_0^3 + \ldots$$

$$\ln (R_0 + \sqrt{1 + R_0^2}) = \ln 2 + \ln R_0 + {}^1/_4R_0^2 + \ldots$$

$$\ln (1 + R_0^2) = 2 \ln R_0 + 1/R_0^2 - {}^1/_2R_0^4 + \ldots$$

We thus have

$$L = \frac{4HP'^2}{\pi E}\Big\{R_0(1 + \nu)\left[\pi - \frac{4}{3}(1 + 2\nu)\right] + \nu(1 + \nu)[\ln R_0 + \ln 2] - \frac{1}{4}(1 + \nu)(7 - 3\nu)\Big\} \qquad (8)$$

for the energy lost in 1 revolution per unit length of roll.

We can simplify equation (8) further by noting that the second two terms within the curly bracket are negligible when compared with the first. For example, if 60 is chosen as a representative value for R_0 and ν is taken as 0.25 (a value valid for most materials), then the first term is 85.5 while the second and third terms are 1.5 and −1.95, respectively. Dropping the second two terms, and setting $\nu = 0.25$ we have

$$L = 5(\pi - 2)HP'^2R_0/\pi E \qquad (9)$$

Let us now replace R_0 by R_1/b and use the expression (4)

$$b = \sqrt{4P'R_1R_2(k_1 + k_2)/(R_1 + R_2)}$$

for the half width of the nip. Here $k_i = (1 - \nu^2)/\pi E_i$ ($i = 1,2$) and the subscripts 1 and 2 refer, respectively, to the roll being considered for energy loss and the roll running against it. Substituting into equation (9) we have

$$L = 2.5\,\frac{\pi - 2}{\sqrt{\pi}}\,HP'^{3/2}\sqrt{\frac{R_1}{R_2}(R_1 + R_2)}\,\sqrt{\frac{E_2}{E_1(E_1 + E_2)}} \qquad (10)$$

for the energy lost in 1 revolution of the fiber-filled roll. The energy lost per second (the power loss) will be found when we multiply by the surface speed S and divide by the roll circumference $2\pi R_1$. When this has been done and R_1 and R_2 have been replaced by the more conventional $D_1/2$ and $D_2/2$, we have for the power loss

$$\text{Power} = 2.5\,\frac{\pi - 2}{\pi^{3/2}}\,HSP'^{3/2}\sqrt{\frac{D_1 + D_2}{2D_1D_2}}\,\sqrt{\frac{E_2}{E_1(E_1 + E_2)}} \qquad (11)$$

Equation (11) gives the power loss for 1 in. of roll. We see that the power requirements are proportional to length of roll face, to surface speed, and to the three-halves power of the nip loading as was anticipated from experimental measurements.

We also see that required power is proportional to H, to $\sqrt{E_2/E_1(E_1 + E_2)}$ and to $\sqrt{(D_1 + D_2)/2D_1D_2}$. Therefore, in order to use equation (11), we must have values for the hysteresis constant H and Young's modulus E. These are the next topics to be discussed.

EXPERIMENTAL DETERMINATION OF THE HYSTERESIS CONSTANT

Let us consider a steel sphere of mass m falling under the influence of gravity from a height h_1 upon the horizontal plane face of a large elastic body composed of the material in a fiber-filled supercalender roll. After impact it will rebound to a height h_2 and the energy lost will be $mg(h_1 - h_2)$. By measuring h_1 and h_2 we will have a direct measure of the loss of energy. If we can then compute the strain energy of the large body in terms of the constants of the experiment, we shall have a measure of H as expressed equation (2).

Huber (*5*) has computed the normal and shear stresses at all points in a semi-infinite elastic body with a plane face when a spherical elastic body is pressed against it. By symmetry it is clear that the stresses at all points within the body will be known if they are determined at all points in a plane passing through the center of the nip normal to the plane face. Let this plane normal to the face be the YZ-plane. The origin of our coordinate system is at the center of the circular nip. The Y-axis is taken in the plane of the face and the positive Z-axis is taken toward the interior of the body. The position of any point in this half plane is given by its Y and Z coordinates. The six stresses are then given by

$$
\left.\begin{aligned}
\sigma_z &= -q_0\left\{\frac{1-2\nu}{3}\frac{a^2}{y^2}\left[1-\left(\frac{z}{\sqrt{u}}\right)^3\right]+\right.\\
&\left.\frac{z}{\sqrt{u}}\left[2\nu+\frac{1-\nu}{a^2+u}u-(1+\nu)\frac{\sqrt{u}}{a}\tan^{-1}\frac{a}{\sqrt{u}}\right]\right\}\\
\sigma_y &= +q_0\left\{\frac{1-2\nu}{3}\frac{a^2}{y^2}\left[1-\left(\frac{z}{\sqrt{u}}\right)^3\right]+\right.\\
&\frac{z}{\sqrt{u}}\left[-2+\frac{1-\nu}{a^2+u}u+(1+\nu)\frac{\sqrt{u}}{a}\tan^{-1}\frac{a}{\sqrt{u}}\right]+\\
&\left.\left(\frac{z}{\sqrt{u}}\right)^3\frac{a^2u}{u^2+a^2z^2}\right\}\\
\sigma_x &= -q_0\left(\frac{z}{\sqrt{u}}\right)^3\frac{a^2u}{u^2+a^2z^2}\\
\tau_{yz} &= -q_0\frac{yz^2}{u^2+a^2z^2}\frac{a^2\sqrt{u}}{a^2+u}\\
\tau_{xy} &= \tau_{xz}=0
\end{aligned}\right\}\quad(12)
$$

where q_0 is the pressure at the center of the nip (maximum value in the nip), a is the radius of the circular nip formed by the two bodies and

$$u = \tfrac{1}{2}\left[y^2+z^2-a^2+\sqrt{(y^2+z^2-a^2)^2+4a^2z^2}\right]$$

Let us now measure the y- and z-coordinates in units of the nip radius a instead of inches. We do this by making the linear transformations

$$x = a\alpha,\ y = a\beta,\ z = a\gamma$$

Then equations (12) become:

$$
\left.\begin{aligned}
\sigma_z &= -q_0\left\{\frac{1-2\nu}{3}\frac{1}{\beta^2}\left[1-\left(\frac{\gamma}{\sqrt{u'}}\right)^3\right]+\frac{\gamma}{\sqrt{u'}}\times\right.\\
&\left.\left[2\nu+(1+\nu)\frac{u'}{1+u'}-(1+\nu)\sqrt{u'}\tan^{-1}\frac{1}{\sqrt{u'}}\right]\right\}\\
\sigma_y &= +q_0\left\{\frac{1-2\nu}{3}\frac{1}{\beta^2}\left[1-\left(\frac{\gamma}{\sqrt{u'}}\right)^3\right]+\right.\\
&\frac{\gamma}{\sqrt{u'}}\left[-2+(1+\nu)\frac{u'}{1+u'}+\right.\\
&\left.\left.(1+\nu)\sqrt{u'}\tan^{-1}\frac{1}{\sqrt{u'}}\right]+\left(\frac{\gamma}{\sqrt{u'}}\right)^3\frac{u'}{u'^2+\gamma^2}\right\}\\
\sigma_x &= -q_0\left(\frac{\gamma}{\sqrt{u'}}\right)^3\frac{u'}{u'^2+\gamma^2}\\
\tau_{yz} &= -q_0\frac{\beta\gamma^2}{u'^2+\gamma^2}\frac{\sqrt{u'}}{1+u'}\\
\tau_{xy} &= \tau_{xz}=0
\end{aligned}\right\}\quad(13)
$$

where

$$u' = \tfrac{1}{2}\left[\beta^2+\gamma^2-1+\sqrt{(\beta^2+\gamma^2-1)^2+4\gamma^2}\right]$$

We now abbreviate equations (13) as follows

$$
\begin{aligned}
\sigma_x &= -q_0A_1\\
\sigma_y &= +q_0A_2\\
\sigma_z &= -q_0A_3\\
\tau_{yz} &= -q_0A_4
\end{aligned}\quad(14)
$$

The total strain energy of the semi-infinite body then is given by the integration of equation (1) over its entire volume:

$$
\begin{aligned}
W &= \int_0^\infty\int_0^\infty\int_0^\infty V_0\,dx\,dy\,dz = a^3\int_0^\infty\int_0^\infty\int_0^\infty V_0\,d\alpha\,d\beta\,d\gamma\\
&= \frac{q_0^2a^3}{E}\int_0^\infty\int_0^\infty\int_0^\infty\\
&\left\{\frac{1}{2}\left[A_1^2+A_2^2+A_3^2\right]-\nu\left[A_1A_2+A_1A_3+A_2A_3\right]+\right.\\
&\left.(1+\nu)A_4^2\right\}d\alpha\,d\beta\,d\gamma
\end{aligned}\quad(15)
$$

in which G of equation (1) has been replaced by its equivalent $E/2(1+\nu)$.

The integrand of equation (15) is a function only of the new independent variables α, β, γ and of Poisson's ratio. With the usual value of ν (= 0.25), the definite integral in equation (15) will have a certain specific value, I, which may be looked upon as a geometrical constant for this problem. We see that the total strain energy W is proportional to the square of the pressure at the center of the nip, q_0^2, to the cube of the nip radius, a^3, and inversely as the value of Young's modulus E.

Let us now go back to the falling ball experiment. We shall show how to compute the radius, a, of the nip formed at the instant of maximum indentation of the steel ball into the large body, following the method of Hertz as given by Timoshenko (*6*).

As soon as the ball comes into contact with the block, compressive forces begin to act, changing the velocity of the ball. If v is the instantaneous velocity of the ball during impact, m its mass, and P the total force the block exerts upon the ball (and vice versa) then

$$m\dot{v} = -P \quad (16)$$

where the dot indicates differentiation with respect to the time t.

In the neighborhood of the contact area there will be local compression in the block, but in the steel ball we assume none because it is very hard compared to the material of the block. The surface of the ball will cause indentation of the block and the amount of indentation, α, is measured by the distance from the undisturbed plane face to the position of a point of the disturbed surface on the z-axis. It is clear that v can be replaced by $\dot{\alpha}$ in equation (16), and we have

$$\ddot{\alpha} = -\frac{P}{m} \quad (17)$$

Timoshenko (*7*) gives a relation between α and the various parameters for the steady-state case. This relation applies to the case of impact as well (*8*) and is

$$\alpha = \left[\frac{9\pi^2}{16}P^2\frac{k^2}{R}\right]^{1/3} \quad (18)$$

in which R is the radius of the ball and k is, as before, $(1-\nu^2)/\pi E$ for the stationary block. When equation (18) is solved for P and substituted into equation (17) we have:

$$\ddot{\alpha} = -\frac{1}{m}\sqrt{\frac{16}{9\pi^2}\frac{R}{k^2}}\,\alpha^{3/2} \quad (19)$$

which integrates into

$$-\frac{1}{2}(\dot{\alpha}^2-v^2) = \frac{2}{5}\frac{1}{m}\sqrt{\frac{16}{9\pi^2}\frac{R}{k^2}}\,\alpha^{5/2} \quad (20)$$

where v is a constant of integration and is the velocity of the ball at the beginning of impact. In equation (20) when $\dot{\alpha} = 0$ (i.e., at the time of maximum indentation) we have

$$\alpha_{max.} = \frac{5}{4}mv^2\sqrt{\frac{9\pi^2}{16}\frac{k^2}{R}} \quad (21)$$

When this value for α is put into equation (18) we get

$$P = \left(\frac{5}{4}\right)^{3/5}\left(\frac{16}{9\pi^2}\right)^{1/5}\left(\frac{R}{k^2}\right)^{1/5}m^{3/5}v^{6/5} \quad (22)$$

The velocity at the beginning of impact is $v = \sqrt{2gh}$ in which h is the height from which the ball is dropped and g is the acceleration due to gravity. Using this with the proper expression (7) for the radius, a, of the nip formed we have

$$a = \left(\frac{15\pi R^2 kmgh}{8}\right)^{1/5} \qquad (23)$$

When the value of P given by equation (22) and the value of a, the maximum nip radius, given by equation (23) are substituted into the relation (9)

$$q_0 = \frac{3P}{2\pi a^2}$$

giving the pressure at the center of the nip, this maximum pressure will be

$$q_0 = \left(\frac{60\ mgh}{\pi^9 R^3 k^4}\right)^{1/5} \qquad (24)$$

When these values for a and q_0 are put into equation (15) and ν is set equal to $^1/_4$ we have

$$W = \frac{8}{\pi^2} Imgh \qquad (25)$$

The constant I can be readily evaluated here because the strain energy W of a perfectly elastic body without hysteresis losses can only be mgh. Thus in equation (25) we see that

$$I = \frac{\pi^2}{8}$$

Since I is a geometrical constant not associated with hysteresis it must have the same value for all semi-infinite bodies for which $\nu = 0.25$. Then equation (25) becomes

$$W = mgh$$

and the loss of energy due to hysteresis will be

$$mg(h_1 - h_2) = H \cdot mgh_1$$

or

$$H = \frac{h_1 - h_2}{h_1}$$

By measuring h_1 and h_2 we will have an experimentally determined value for the hysteresis constant H. To get a reliable estimate of the value of H we should measure it when the stresses have the approximate values of those encountered in the nip of a supercalender stack. The unit loading at the center of a nip in normal supering is of the order of 10,000 p.s.i. To have stresses of this magnitude in equation (24) in the falling ball test requires that the drop height be about 0.005 in. It is impractical to do this by direct drop but we can drop the ball through this small distance by suspending it at the end of a long thin wire. If l is the length of the wire and C is the horizontal distance the ball is drawn out from its position of equilibrium at which point it just touches the face of the block under test, the height through which the ball falls is given very closely by

$$h = \frac{C^2}{2l}$$

Consequently, if h_1 is the initial height (from which the ball is dropped) and h_2 is the height to which it bounces, the hysteresis constant will be given by

$$H = \frac{C_1^2 - C_2^2}{C_1^2}$$

It turns out in a great number of experiments that the value of H is between 0.2 and 0.25. We shall use the value $H = 0.23$.

EXPERIMENTAL DETERMINATION OF THE ELASTIC MODULUS

Using the results of elasticity theory as applied to the general case of two elastic bodies being pressed together, we can devise a way of determining the modulus of elasticity. When a hard spherical surface is pressed against a relatively soft cylindrical surface, the contact area will have an elliptical boundary with semiaxes a and b, given by (10)

$$\left.\begin{aligned} a &= m\sqrt[3]{\frac{3\pi Pk}{4(A+B)}} \\ b &= n\sqrt[3]{\frac{3\pi Pk}{4(A+B)}} \end{aligned}\right\} \qquad (26)$$

In these equations m and n are functions of an angle θ defined as $\cos^{-1}(R_s/[R_s + 2R_c])$, where R_s and R_c are the radii of curvature of the sphere and cylinder, respectively, P is the total force the sphere exerts on the cylinder, k is the elastic constant $1 - \nu^2/\pi E$ of the cylinder and A and B are defined by the relation $A + B = (R_s + 2R_c)/2R_sR_c$.

The values of m and n for various values of θ are given in Table I (11) below.

Table I. Elastic Constants

θ, deg.	m	n	θ, deg.	m	n
30	2.731	0.493	65	1.378	0.759
35	2.397	0.530	70	1.284	0.802
40	2.136	0.567	75	1.202	0.846
45	1.926	0.604	80	1.128	0.893
50	1.754	0.641	85	1.061	1.000
55	1.611	0.678	90	1.000	1.000
60	1.486	0.717			

Using only the first of equations (26) we have

$$E = (1 - \nu^2)\frac{3}{4}\frac{m^3}{a^3}\frac{P}{A+B} \qquad (27)$$

If we can determine the value of a in the right-hand side, we shall then be able to calculate the elastic modulus E.

To do this we devised an instrument which we call an optical hardness tester. An important feature of this instrument is that it leaves no mark on the roll being

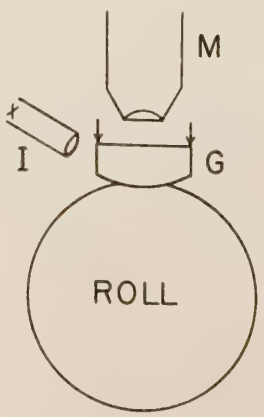


Fig. 3. Optical hardness tester

tested. The instrument is shown schematically in Fig. 3. In the figure G is a glass lens with one plane surface and one spherical surface; the arrows represent the force used to press the spherical surface against the roll. Light from an illuminator I is incident on the center part of the spherical glass surface at an angle greater than the angle of total reflection, and thus all light will be totally reflected except in the nip area where the roll makes optical contact with the glass. In this area some light will be transmitted into the roll surface and then scattered. This process renders the nip area readily visible in the calibrated microscope M where its dimensions are measured.

It should be pointed out that the supercalender roll must have a smooth uniform surface at the point of measurement if the contact area is to be measured successfully. If the nip is not a good ellipse, it is because of surface irregularities of the roll, and the measurements on such nips should be discarded. Several measurements should be taken and the average value used in equation (27). Even with these precautions the degree of accuracy leaves something to be desired.

When many measurements were made on typical rolls, values for E were obtained which lie between 3×10^5 and 6×10^5 p.s.i. We take $E_1 = 5 \times 10^5$ p.s.i.

Going back now to equation (11) and putting in the values $H = 0.23$ and $E_1 = 5 \times 10^5$ and remembering that E_2 ($= 3 \times 10^7$) is large compared to E_1 we have

$$\text{Power} = 1.25 \frac{\pi - 2}{\pi^{3/2}} \frac{0.23}{\sqrt{5 \times 10^5}} SP'^{3/2} \sqrt{2 \frac{D_1 + D_2}{D_1 D_2}}$$

$$= 1.67 \times 10^{-4} SP'^{3/2} \sqrt{\frac{D_1 + D_2}{2D_1 D_2}}$$

The units of power in this equation are inch-pounds per second per inch of roll face; the units of speed are inches per second; the units of nip loading P are pounds per linear inch of roll face; the units for roll diameters are inches.

When we express S in thousands of feet per minute P in thousands of pounds per linear inch, and power in horsepower we have:

$$\text{Horsepower/inch} = 0.160 SP'^{3/2} \sqrt{\frac{D_1 + D_2}{2D_1 D_2}} \quad (28)$$

This is the horsepower generated in the fiber-filled roll in a steel roll-fiber roll nip.

If we have two fiber-filled rolls running against each other, $E_1 = E_2$ so the horsepower generated in this nip will be

$$\text{Horsepower/inch} = 0.160 \sqrt{2}\, SP'^{3/2} \sqrt{\frac{D_1 + D_2}{2D_1 D_2}}$$

$$= 0.226 SP'^{3/2} \sqrt{\frac{D_1 + D_2}{2D_1 D_2}}$$

We can now compute the power requirements for a supercalender stack by adding together the requirements for each nip. As an example let us compute the power required to operate Niagara Falls no. 7 supercalender shown in Fig. 4. The value of $\sqrt{(D_1 + D_2)/2D_1D_2}$ is 0.197 for the top nip, 0.194 for the bottom nip, and 0.247 for each of the six intermediate nips. There are no fiber-fiber nips in this stack, so we require the sum of the eight square roots; this sum is 1.87. The load applied at the top of this supercalender is 2000 lb. per in., giving a middle nip load of 2500 lb. per inch (arrow). Only a small error is introduced by assuming the middle nip load at each nip. Using a speed of 1000 f.p.m. and equation (28), we have

$$HP = 0.16 \times 1 \times (2.5)^{3/2} \times 1.87$$

$$= 1.18$$

In Fig. 5 are shown six roll arrangements in Kimberly-Clark supercalenders. For each of these stacks the sum of the factors $\sqrt{(D_1 + D_2)/2D_1D_2}$ for each nip has been calculated, taking due account of those nips which are fiber-fiber nips. This sum Σ is given in Fig. 5 for each stack, along with the measured horsepower HP for that stack. According to equation (11) the ratio Σ/HP should be a constant, and we see that it is within a reasonable experimental error except for the Kimberly no. 6 stack.

The first five stacks shown in Fig. 5 had fiber rolls filled with grade W Riegel blue calender paper. The Kimberly no. 6 stack was filled with no. 1 white Fox River calender paper, and this paper is known to be "softer" in having a somewhat lower elastic modulus and a somewhat higher hysteresis constant.

A good confirmation of the theory has thus been obtained because the list of five blue-roll supercalenders includes stacks having from seven to ten rolls of widely different diameters, lengths, and arrangements.

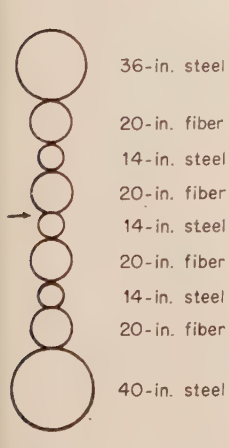


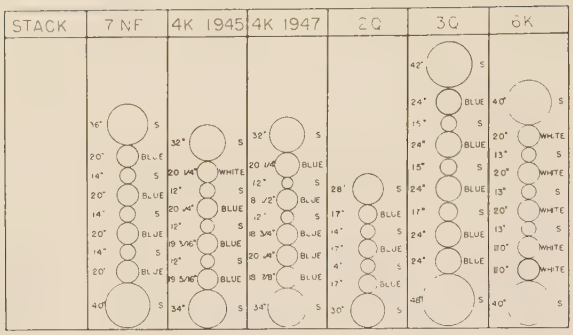
Fig. 4. No. 7 Niagara Falls super

TEMPERATURE DISTRIBUTION IN A FIBER-FILLED SUPERCALENDER ROLL

We have seen in previous sections something of the mechanism by which heat is generated in supercalender rolls. In this section we shall discuss the distribution of temperature in a fiber-filled supercalender roll under running conditions in an effort to contribute to a better understanding of "burnouts" and "charring." Burnouts occur occasionally when nip loading and speed are both excessive and are evidenced by small "explosions" somewhere below the roll surface with resultant fairly deep holes in the surface. When these occur, the roll must be discarded. Charring is found when a roll is stripped for refilling and is evidenced by a discoloration of the material, usually from $^3/_8$ to $^1/_2$ in. below the roll surface.

If A calories of heat are generated per second per unit volume at a point (x, y, z) in a homogeneous isotropic medium, the temperature U will satisfy the partial differential equation (12)

$$\frac{\partial U}{\partial t} = \frac{\kappa}{\rho s} \nabla^2 U + \frac{A}{\rho s} \quad (29)$$



Roll face, in.	191	154	154	154	228	137
Measured hp./in.	1.28	1.27	1.36	0.97	1.34	1.65
$\Sigma\sqrt{(D_1+D_2)/2D_1D_2}$	1.873	1.953	2.087	1.452	2.026	2.216
Hp./in./Σ	0.68	0.65	0.65	0.67	0.66	0.75

Fig. 5

in which ρ is the density, s the specific heat, κ the thermal conductivity, and t the time. In equation (29) A is assumed uniform in time. In our case a certain definite amount of heat is generated in each unit volume each time it passes under the nip. For purposes of calculation we shall assume that the rate A is uniform in time and of such a magnitude that during the time of 1 revolution it will total up to the amount generated in one passage through the nip.

In our case of a supercalender roll, it will be advantageous to write equation (29) in cylindrical coordinates. When we do this, equation (29) becomes

$$\frac{\partial U}{\partial t} = \frac{\kappa}{\rho s}\left\{\frac{\partial^2 U}{\partial r^2} + \frac{1}{r}\frac{\partial U}{\partial r} + \frac{1}{r^2}\frac{\partial^2 U}{\partial \varphi^2} + \frac{\partial^2 U}{\partial z^2}\right\} + \frac{A}{\rho s} \qquad (30)$$

At this point in our discussion we shall not be concerned with transients but shall limit our study to the steady-state case, i.e., we set $\partial U/\partial t = 0$. Also, since the roll is long compared to the radius and the nip loading is uniform, it is entirely reasonable to assume that over most of the roll there will be no axial flow of heat. Then we can set $\partial^2 U/\partial z^2 = 0$. Because of axial symmetry, the temperature will not be a function of orientation, i.e., $\partial^2 U/\partial \varphi^2 = 0$. Under these conditions equation (29) reduces to

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right) + \frac{A}{\kappa} = 0 \qquad (31)$$

The rate of energy absorption at a given point has been shown to be $H \cdot V_0$ per stressing cycle (i.e., per revolution). The energy absorption per second will be

$$H \cdot V_0 \cdot \frac{S}{2\pi R_1}$$

where S is the surface speed of the roll and R_1 its radius. When this rate of energy absorption is expressed in calories we have

$$A = \frac{SHN}{2\pi R_1} V_0$$

where N is the number of calories in the unit of energy in which V_0 is expressed. Substituting this for A in equation (31) and integrating twice we have

$$U = -\frac{SHN}{2\pi R_1 \kappa}\int \frac{1}{r}\,dr \int r V_0\,dr + C_1 \ln r + C_2 \qquad (32)$$

The constants of integration C_1 and C_2 must be chosen to fit the boundary values of the problem. Normally a fiber roll runs between two steel rolls so that there are two nips involved and the first term of equation (31) must be multiplied by a factor of two.

We have used equation (32) in arriving at the temperature distribution of a fiber-filled roll 20 in. in diameter running at 1000 f.p.m. (200 in. per sec.) between two steel rolls of 13 in. diameter at a nip loading of 2500 lb. per lineal in. The modulus of elasticity of the fiber-filled roll was taken as 5×10^5 p.s.i., the hysteresis constant as 0.2, the thermal conductivity as 0.0007 calorie in. per sq. in. sec. 1°F., the conversion factor N as 0.027 calorie per in.-lb. To establish the boundary conditions we assumed that the paper being supered carried away the heat reaching the surface at such a rate that the temperature of the roll surface was maintained at 200°F. and that the shaft of the fiber filled roll (assumed to be $14^1/_2$ in. diam.) was maintained at 150°F. The boundary conditions then were

$$\text{at } r = 10 \text{ in.} \qquad U = 200°\text{F.}$$
$$\text{at } r = 7.25 \text{ in.} \qquad U = 150°\text{F.}$$

It will be seen in Fig. 6 that the maximum temperature of about 360°F. occurs about 0.6 in. below the roll surface in the steady-state case. The height of the maximum depends on the value of the thermal conductivity that is chosen. We decided upon the value 0.0007 calorie in. per sq. in. sec.°F. in quite an arbitrary fashion. The "Handbook of Chemistry and Physics" gives a value for "paper" of 0.0005 calorie cm. per sq. cm. sec.°C. We reasoned that since this fiber filling had been pressed to quite a high density, its thermal conductivity had been increased. We defend our choice of 0.0007 only as to order of magnitude. However, the position of the maximum changes only very slowly with the thermal conductivity. For example, if $\kappa = 0.0007$, the maximum occurs 0.55 in. below the surface; while if $\kappa = 0.0014$, it is 0.59 in. below the surface. We feel that this position is quite well established.

We shall now show how the transient case is to be solved. Assuming radial flow of heat, only, equation (30) reduces to

$$\frac{\partial U}{\partial t} = \frac{\kappa}{\rho s}\left\{\frac{\partial^2 U}{\partial r^2} + \frac{1}{r}\frac{\partial U}{\partial r}\right\} + \frac{A}{\rho s} \qquad (33)$$

If we differentiate this equation partially with respect

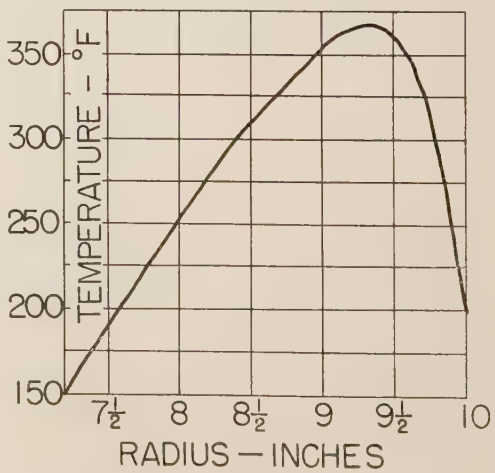


Fig. 6

to the time t, remembering that A is a function of r alone, we get

$$\frac{\partial^2 U}{\partial t^2} = \frac{\kappa}{\rho s}\left\{\frac{\partial^3 U}{\partial t\,\partial r^2} + \frac{1}{r}\frac{\partial^2 U}{\partial t\,\partial r}\right\} \qquad (34)$$

Assuming the solution U made up of the product of two quantities, one a function of t alone and the other a function of r alone, say $U = T(t)\cdot R\,(r)$ we obtain

$$\frac{d^2T}{dt^2}\Big/\frac{dT}{dt} = \frac{\kappa}{\rho s}\left\{\frac{1}{R}\frac{d^2R}{dr^2} + \frac{1}{rR}\frac{dR}{dr}\right\} \qquad (35)$$

If this equation is to be true for all values of the independent variables r and t, each side of equation (35) must be equal to a constant, $-Q$, and we have two equations

$$\left.\begin{aligned}\frac{d^2T}{dt^2} &= -Q\frac{dT}{dt}\\ r\frac{d^2R}{dr^2} + \frac{dR}{dr} + Q\frac{\rho s}{\kappa}Rr &= 0\end{aligned}\right\} \qquad (36)$$

The first of these integrates into

$$T(t) = c(1 - e^{-Qt}) \qquad (37)$$

and the second can be integrated in terms of Bessel functions. We have not carried out the numerical calculations to arrive at a set of temperature curves for the transient case as t increases without limit. We see from equations (36) and (37) that the maximum of the temperature curve will approach its final position and value exponentially with time.

Figure 7 shows the relative rate of heat production as a function of the radius. If we start with a uniform temperature roll, it seems reasonable that shortly after the roll starts, the maximum of the temperature curve will be located close to the surface because of the much greater rate of heat production as the surface is approached. As time goes on the position of this maximum will proceed away from the surface exponentially with time so as to approach its final value at about 0.6 in. below the surface. If the heat production which depends upon the speed and the $^3/_2$ power of the nip loading is great enough, the burnout temperature will be reached while the maximum of the temperature curve is still considerably shallower than 0.6 in. Thus, in a qualitative fashion, we arrive at the conclusion that burnouts and charring can be expected to occur somewhere between the surface and 0.6 of an inch below the surface depending upon the rate of heat production.

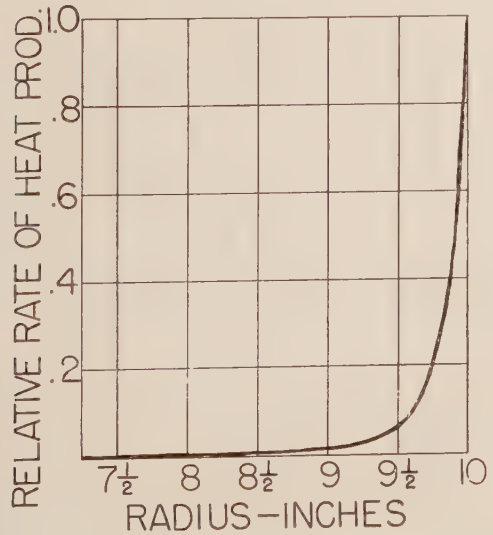


Fig. 7

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DISCUSSION

THURSDAY SESSION, SEPT. 23, 1954

The third panel discussion and question period convened at 3 p.m. A. J. Stamm, moderator, presiding.

Moderator Stamm: To open the panel I would first like to introduce the various discussion leaders that are added to our panel. The first one is Mr. Brecht (Darmstadt) who will discuss Mr. Gallay's paper when his turn comes. The next is F. B. Schelhorn (National Container Corp.) who will discuss the paper of Mr. Nissan. And the third one is Mr. Tongren (Hammermill Paper Co.), who will discuss the paper of Mr. MacLaurin and Whalen and last, M. N. Davis (Kimberly-Clark Corp.), who will discuss the paper of Mr. Burkhard.

Two of our papers this morning had two authors. According to general practice only one man gives the paper, but we have asked both co-authors to join us on the platform, to contribute to the discussion. So, first, I would like to introduce Mr. Gallay's associate, L. M. Lyne. And next, Mr. Burkhard's associate, Peter Wrist.

Our group feels that the best way is not to jump from one paper to another, but rather to discuss one at a time.

Now, with that introduction we will start with the discussion of the paper of Mr. Gallay.

This noon, while talking with him, several of us felt that there was a little misunderstanding in his use of the term "surface tension." I would like to have Mr. Gallay clarify his use of this term before calling for questions.

Gallay: I am sorry that there apparently was some misunderstanding on this question. I suppose that I assumed implicitly that everyone would understand that there was no direct or immediate connection between the surface tension I was talking about and the surface tension that is concerned with the very last portion of the strength development curve, say beyond 80% solids. Actually these are simply quite different applications of the same physical force.

In the case of the last portions of water, we know that we have extremely strong, highly localized surface tension forces which draw the adjacent surfaces of the fibers together and bring them close enough together so that hydrogen bonding can take place. The magnitude of this surface tension was measured many years ago in classical researches by Boyd Campbell.

We, on the other hand in these earlier stages of water removal, are dealing with quite another application of surface tension. We are talking about water envelopes surrounding bundles of fibers. In our concept, not only are the fiber

bundles interconnected, but these water films are also interconnected to the point of maximum surface energy. We are talking about forces of lower magnitude, which are more diffuse as far as the fibers are concerned. Therefore, you can see that there is no conflict and that each one stands on its own merits and can be considered quite independently.

Moderator Stamm: I am glad to get this explanation. It will help.

We will now turn to Mr. Brecht and have him ask some of the questions of his own and any others that he may have received from the audience, and then we will open the discussion.

Brecht: The subject matter with which Mr. Gallay dealt is intensely important from both the practical as well as the scientific point of view. This subject is not only of extreme importance, but it holds the utmost fascination for the research worker.

The manufacture of paper begins with the pulp suspension and ends with the dried paper at the reel. Now, it would appear to me that for the first time we are enabled to survey the whole development of this structure in its successive phases and are beginning to obtain a coherent and unified concept of the process from beginning to end. Previous work in this field was highly empirical in its nature and was directed to the strictly practical needs in paper machine operation.

With the continued increase of machine speeds, breaks are becoming more and more a serious problem, and to a larger extent they are associated with the wet-web region. It therefore became necessary to direct some attack to this problem, even if only on a practical rather than a theoretical basis.

It is probably correct to say that the vacuum pickup has offered a partial solution to the general problem, but then even from the practical point of view part of the problem still remains unsolved and will be aggravated by still higher machine speeds in the future.

There can be no doubt in the minds of any of us that the type of scientific work directed to this problem by Mr. Gallay is what we must have in order to give us a broad basis of understanding of the subject, which, in turn, will lead to further progress on this matter.

There are several questions of general interest which have occurred to me and I will put them to Mr. Gallay first.

1. What role is actually played in the wet-web regions by frictional resistance of the fibers? What does he mean when he says that frictional resistance is superimposed and on other operative forces?

2. If surface tension, as you put it, Mr. Gallay, is a major factor in the early position of the wet-web region before the inflection point, what effect have the various stock components on the wet-web strength obtained?

3. Is my understanding correct that the wet-web strength has a maximum in the inflection region, where the surface tension has decreased comparatively little and at the same time the fiber bending has reached an appreciable value?

4. Is it conceivable to consider that fiber bonding is appreciable at this low solid content of about 20%?

5. Is it possible for Mr. Gallay to give us some sort of outline of these characteristics of the web which will give the optimum strength at about 20% solids?

I want to emphasize again my opinion that this work of Mr. Gallay's, together with the assistance of Mr. Lyne, is a classic in this field, and I am sure that it will be regarded as such in future research.

Gallay: About 2 years ago this Summer our Canadian technical section invited Professor Brecht over to a special conference which was held in conjunction with our Summer meeting. Unfortunately he was not able to attend, but he did send along a paper in German, which I had the privilege of translating and presenting for him. It was at that time that I really became very much interested in this wet-web strength problem. I am sure that there is no doubt in the minds of any of you that in this field Mr. Brecht is most certainly the pioneer.

I would like to thank you, Professor Brecht, for your very kind remarks concerning our paper.

Now, to deal with your questions. I believe that the first one dealt with frictional resistance.

Frictional resistance among fibers will be obtained, I think, over the whole range of the web structure from the very wet end to the dry end.

I think it is fair to say, and as Mr. Mason has shown us not only this week but on previous occasions, that way back in very dilute pulp suspensions, going down to several hundredths or even thousandths of a per cent, entanglement and interference among fibers are already obtained, which is the beginning of what we would later term frictional resistance to pulling out by tensile or other forces. Now, as the web continues to dry, this frictional resistance will continue to increase until it reaches, as one would expect, its greatest magnitude at the dry end of the process.

You will have noticed the magnitude of the effect of the frictional resistance at the dry end of the glass fiber curve, which I showed you this morning. Similarly, with the pulp webs in a nonpolar solvent, you will have noticed that there was a considerable residual of the strength left, which must be ascribed in such a nonbonding medium to frictional resistance to pulling-out.

We performed several experiments some years ago, which have not been published but which dealt with the same matter.

It is well known that if pulp sheets are made in a nonbonding medium very little strength is obtained. The researches that I have seen published in this connection were always concerned with unbeaten fibers. In our experiments, we beat the pulp quite heavily in water over a range of freeness and then effected the final manufacture in a medium which would obviate bonding. We then obtained quite a respectable amount of strength even though we could assume with a reasonable degree of safety that there was little or no bonding.

One would expect that the effect of the beating would be such that it would increase the amount of frictional resistance to pulling apart of the fibers.

Now, with regard to the second part of that first question of Mr. Brecht's. In that regard I would like to repeat that this frictional resistance exists throughout the history of the web and therefore, like the poor, we consider it always with us. The other operative forces are therefore additives to the frictional resistance which is always present.

The second question, just to refresh your memory, dealt with the effective components of stock. We did nothing on that question. No work was carried out by us on different types of stock to see whether improved effects could be obtained.

I imagine that here Professor Brecht is thinking mainly about his own work, which has dealt to a large extent with mixtures of various pulps and pulp fractions and the measurement of the wet-web strength of these mixtures in order to attain the highest possible wet-web strength.

On the third question, with regard to conditions obtaining in the inflection region, his understanding is quite correct.

The first inflection point represents, in our opinion, the maximum in surface tension, together with the attainment of an appreciable amount of inter-fiber bonding.

The fourth question dealt with the conceivability of inter-fiber bonding at these very high moisture contents.

We consider, possibly with a good deal of temerity, that this is not only conceivable and we have a good deal of evidence for it.

We could elaborate on that subject, of course, for a considerable time. If the statement is made that you cannot possibly have inter-fiber bonding at an early stage of wet-web development, you are saying, in effect, in my opinion, that the surface

of the fiber is nontacky, because it is obvious to me, at least, that if you have a degree of tackiness, or a disorganization at the surface, you must necessarily get a degree of adhesion.

I would like to draw on a very simple analogy for this reasoning. There are many analogies which could be adduced to this question, but this one alone might serve the present purpose.

Let us take the case of starch, for example, which shows a remarkable similarity to cellulose in many respects and which differs from the cellulose fiber mainly with respect to the shape of the individual entity and the form of crystallization. Sedimentation experiments on a normal starch suspension in water show a low sedimentation volume. Under a microscope, with the aid of a fine glass needle, it can be readily shown that the granules show no inclination whatever to adhere to one another. If, however, the same experiments are performed with starch granules which have been bruised by some simple mechanical means, the results obtained are quite different.

The suspensions of the bruised starch granules show a high sedimentation volume. Under the microscope the granules show very marked tendencies to adhere to one another. In suspensions, this leads to structures and consequently higher sedimentation volumes.

Bruising results in a disorganization at the surface, a disruption of the crystalline organization. Swelling by water ensues and the portion of the surface of the granules becomes tacky which results in adhesive properties.

I see no reason why we should not regard cellulose fibers in the same light. The pulp fibers, even in the unbeaten state, have been exposed to a series of mechanical treatments in processing, and there appears to be a considerable likelihood of some disruption of the crystalline organization on the surface of these fibers. In my view, such disruption must produce a degree of tackiness which, in turn, will represent a capability of adhesion. In the wet-web region, we are of course considering inter-fiber bonding of a far weaker order than in the case of the inter-fiber bonding obtained toward the dry end of the papermaking process. Nevertheless, the degree of strength attained through inter-fiber bonding in the wet-web region is very appreciable and, as we have attempted to show, forms a very important part of the whole strength mechanism in these earlier stages of the web development.

The last question of Professor Brecht dealt with the possibility of improving the wet web strength at the inflection point.

We will assume that surface tension cannot be increased. Actually there are some materials which increase the surface tension of water but other difficulties are involved. For example, a saturated solution of potassium carbonate yields a surface tension over a hundred dynes, but when this was tried as a medium, the alkalinity was such as to affect the fiber appreciably chemically and this method was abandoned.

We cannot, therefore, improve the wet-web strength by increasing surface tension. We can, of course, increase the level of inter-fiber bonding and of fractional resistance by beating or wet pressing. The use of longer fibers will increase frictional resistance. The diameter of the fiber will also be of considerable importance, as I showed in conjunction with glass fiber webs this morning.

Now, it is very difficult to change the diameter of a chemical pulp fiber, but there are distinct possibilities of doing so in groundwood, a subject with which, of course, Professor Brecht has been particularly concerned.

Now, have I answered your questions?

Brecht: Yes; very well; splendidly.

Moderator Stamm: Do you have any further questions of your own before we call for questions from the floor?

Brecht: No, thank you, Mr. Chairman. Thank you very much.

Moderator Stamm: Mr. Clark, I imagine you have a question.

J. d'A. Clark: If I may perhaps come up to the board for a moment. I have no more than a question, if you will allow me a few moments. I want to congratulate Mr. Gallay and Mr. Lyne on this elegant wealth of data which we have before us today.

However, I was sorry to hear Mr. Gallay say so explicity he dissociates himself from the fibrillar school of thought and is of the plastic school of thought. Personally, I favor the fibrillar school.

We have some questions propounded by Mr. Brecht, and I was waiting for Mr. Gallay to answer them from his point of view. I'm still waiting for the answers.

Now I'm going to examine a somewhat similar set of questions and answer them from the fibrillar school of thought.

If we plot the tensile strength against moisture for an unbeaten pulp fiber sheet, we get a rising curve with a flat in the center. But if we have a beaten fiber, we get it like that (straight up without the flat); and if we plot a curve of fine glass, we get something like a sharp inverted V; and for coarse glass, something like that a flat inverted V (continuing to draw on blackboard). The inflection point of all the curves occurs somewhere between 20 and 30% solids.

Now, why do we get the inflection point at all? What is it all about? And I defy you to explain them unless by the fibrillar theory.

For example (using blackboard), we have two long, thin cylinders, representing two fibers. It is clear, if you have a lot of water between them, they will easily slide apart, corresponding to little or no strength and in this lower part of the curve.

As this water goes away, you will get a rapid increase in strength, and you will notice all these curves are more or less parallel for all the fibers, since surface tension has the same effect for all. The surfaces get closer together as the moisture leaves, and you come to the point here where there is continuous adhesion between the fibers with a minimum amount of lubrication by the water, and that occurs somewhere between a solids content of 20 and 30%.

Now, when you dry the fibers beyond that point, instead of being bound all the way along, between, the fibers start to let go; the water has dried away from them. Consequently, as more water goes away you get a rather rapid drop with glass.

On the other hand, with the unbeaten pulp, you have a certain amount of fine fibrillae present, and they hold that water more tenaciously because of their fineness; and consequently you find, with a small amount of fibrillae between the fibers, they bind together slightly, and they hold the fibers together, and ultimately, as the dryness increases, they lock and you get a normal papermaking bond.

In the case of a beaten pulp, we have a lot of fibrillae there, both coarse and fine, so you don't have the sudden transition points around the 70 to 80% moisture level, and consequently you get a smooth rising curve for beaten pulp.

Moderator Stamm: Mr. Gallay, would you like to answer Mr. Clark?

Gallay: I would like my associate, Mr. Lyne, to tell you briefly about one little set of experiments we did, which I think is quite relative to this subject.

L. M. Lyne (The E. B. Eddy Co.) (using blackboard): One would expect in a case such as Mr. Clark has just outlined that you would have a sudden failure as the load increased, if there is an actual breakdown of water film between the two fibers.

We performed a very simple experiment in the laboratory using our wet-web tester, and attaching to its two heads microscope plates, one to each head (drawing on blackboard), and putting a drop of water between these plates, and measuring the increase in load and elongation as we separated the head.

And the plot of the development of strength was—this is load—elongation (indicating)—there was an immediate rise

in load to a definite level, and a sudden break in that load with practically no elongation.

After the separation of these plates, we replaced them, and of course there had been an evaporation of some of the water from this interface.

The next load went up higher and broke.

And this continued to a maximum break; and after replacing the plates the next time, the load dropped to a lower level.

Finally there was elongation without load.

This type of rupture would be the type expected if it were purely a matter of the drying up of the water between those two faces; and in the work shown this morning, on the stepwise development of strength in the glass fibers, there is a conceivable relationship between these experiments and what Mr. Clark has just been discussing.

CLARK: One point I want to make—one observation: I should have made this, in the case of the glass, that stepwise movement I think is clearly due to the difference between dynamic and static friction. You build up to the point where it moves, and suddenly the thing locks; and you don't get that type of thing very well on the beaten pulp. I think that is your stepwise movement that causes it.

LYNE: We feel that that stepwise movement is not one of friction as much as a rearrangement of the water film interfaces, i.e., the water-air boundaries in the web of glass, which readjust themselves after the sheet has elongated a certain distance, and therefore build up sufficient surface tension forces to give complete resistance to load; until you have overcome that newly regrouped force.

CLARK: That is what I call a coefficient of friction. I quite agree with you.

RANCE: First, I must join the earlier speakers in paying tribute to the pioneer quality of this wonderful bit of work.

At the same time I was very glad to get Mr. Gallay's extra statement about surface tension because like Mr. Stamm and others, I wasn't very happy about that question of surface tension.

It seems to me that the biggest forces of surface tension build up in the later stages of the water removal, quite a long way from the 20% solids region, and consequently I want to ask Mr. Gallay whether it is possible these two successive phases are not surface tension followed by bonding, but two different phases of surface tension consolidation.

Perhaps the first is succeeded by the second phase when air starts going into the stock.

I suggest in fact that bonding may not occur until we have reached that 20 to 30% of water which Mr. Clark was talking about. In fact his figure relates to 20 to 30% of water and not to 20 to 30% of solids.

GALLAY: We are of the opinion on the basis of several pieces of evidence that have been provided this morning that there is actually a sharp decrease in this type of surface tension after you pass through the inflection point of approximately 20 to 25% solids.

We know, that in the glass fiber experiments, by the introduction of extraneous bonding agents were able to simulate the strength development curve for pulp. That in itself is strong evidence for the existence of inter-fiber bonding at these low levels of solids.

I find it difficult to conceive of an extension of surface tension forces throughout the major portion of the strength development range. We know that surface tension is important up to about 20 to 25% solids, and we have strong evidence to show that it decreases sharply after that range. We fully realize the importance of surface tension in conjunction with the final inter-fiber bonding above 75% solids. As I explained earlier, these two manifestations of surface tension are vastly different in nature. One is a water envelope holding fibers together, the other draws together two fibers at their adjacent surfaces. As I explained earlier also, I find it not at all difficult to conceive of adhesion among fibers in a wet system. It is not bonding in the same sense as that used by Mr. Rance, but if the degree of adhesion is there, then obviously a degree of strength is added to the system.

LYNE: I would like to add to the remark concerning the introduction of air by calculation of the bulk of the sheet and the amount of pulp and water present. It appears that the air is introduced into the sheet at a very low stage of the solid, around 12 to 15%, and this therefore would intensify the water-air interfaces, which gives rise to this rather steep increment in strength.

IVARSSON: There is one thing that I particularly noticed in all work of this kind and that is that everybody, including myself, stressed all the data in just load—that is, force against elongation and that is actually a very serious thing and particularly if you study wet webs, where actually the air during the test changes tremendously and I should like to hear your opinions on that.

GALLAY: I understand exactly what you mean, Mr. Ivarsson.

We realize, of course, that during these load-elongation curves there is a necking down—i.e., a change in the cross section of the test strip. However, because of complications involved in the measurement we did not extend our effort toward putting the load on a per square inch basis.

From a structural point of view, there is no doubt that this should be done. However, from the point of view of the generalities that we wished to bring out, we felt that it would not be worth the tremendous trouble that it would take to measure accurately those changing cross sections, assuming that it could be done at all.

IVARSSON: But you do get completely different results.

GALLAY: I am afraid that I have no information as to how different the results would be.

MODERATOR STAMM: Are there any further comments from the floor?

BOADWAY: There is only one suggestion that I would like to offer here with regard to this surface tension matter and that refers to the maximum, particularly with glass—I was wondering if Mr. Gallay had done any calculations on the contact angle and that the maximum might coincide with optimum contact angle with the result that the sum would tend to pull the fibers together and when water was present. With excess water present, the contact angle would be unfavorable because the curvature would almost be normal to the surface of the fiber. On the other hand, as the water decreased beyond an optimum point, the situation realized would be a reduction in the actual area that the water contacted. Possibly I could draw a few diagrams on the board in order to explain that.

GALLAY: We did not measure any contact angles. Our glass fibers were clean, and we assumed that the contact angle was zero. That is the answer to the question.

The pictures that have been put on the board by the questioner remind one of the three-phase system where you can get just that sort of thing.

If, for instance, you have cellulose pulp fibers in a system consisting mainly of a nonpolar liquid, but containing a small amount of water, the water surrounding the fibers will obviously bring about an intense flocculation, as many of you know, because of that same sort of mechanism.

However, where we have a two-phase system, other than air, that is just fibers and water, and where we consider that the wetting is complete, we made no measurements of the contact angles.

Now, I wonder if I might continue, Mr. Chairman, since Professor Brecht has passed me two questions from the floor?

The first one is from F. T. Ratliff of Personal Products Corp. He asks, "Would you care to discuss the possible implications of the fact that your instrument could not record the true load elongation curve once the peak load has been passed."

Now, what Mr. Ratliff is referring to is this sort of a load-elongation curve (indication). You will recall that the load-elongation curves rise for the first section and then following a "yield point, there is a plastic section prior to failure."

If, however, you are using a constant rate of strain and you are using a very slow rate, then such a load-elongation curve can rise and to a partial failure following which there will be a residual load required as the path continues toward complete failure. Therefore, instead of cutting off the area under this curve (indicating), you are actually doing more work on this system after this peak has been reached.

The answer to the question is that we got no such effects because, first of all, we were using a constant rate of loading and, second, presumably our rate of loading was much too high to get this sort of effect.

I presume also, that Mr. Ratliff, from the point of view of his company's endeavors, got such effects on dry crepe tissues and on such grades particularly; of course, you would expect to get that sort of data at low rate of loading.

One more comment on this question. I just learned last night in a conversation with Professor Brecht that the September 5 issue of *Das Papier*, which I have not seen as yet and which will probably reach my desk while I am here this week, contains an article by Professor Brecht in which he has measured stress strain on load-elongation curves on wet webs. I am very sorry that I did not have an opportunity to see this before. I am happy, on the other hand, from the glance that I took at this publication, that his data within their scope certainly confirm the observations that I made this morning.

I have one other question and it has no name on it.

"In your load-elongation work, what effect does the rate of load application have on the general results discussed?"

I will ask Mr. Lyne to answer that.

Lyne: With our equipment the rate of loading was limited to 2 to 20 grams per sec., which is a relatively narrow range, and within that range we found practically no divergence in the result. We obtained the same failure load and almost the same elongation at the lower rate. At the lower rate there was an indication of greater elongation at the break.

Steenberg: We have been working on the load-elongation curves at quite different rates, from the extremely small up to the very high speed, and I think that perhaps the information that the writer of that question wanted was not in your specific case but as to what he could generally expect.

Now, to make it short, at the rates where the shock waves are not present you do not get any real big difference, which means, in short, that you have to have rates of elongation of the order of over 5 meters per sec. on the standard shape before you get into the new region of impact strength. However, up to regions of the order of, say, half a meter a second on the standard length strip, say, a 200-mg. strip or something like that, you will not find any important changes.

I thought that this was some information which I should put into the record.

Moderator Stamm: Are there any other questions?

Shoumatoff: This is a question and a very trivial one but I understood previously that the point of inflection is a point of maximum slope. On these curves, the point in question is really a flattening of the curve, which is called a stationary point. Is that correct?

Gallay: Possibly I used the word inflection incorrectly. By the term I intended to mean a change in the slope regardless of whether it flattened out or whether it proceeded more steeply upward.

Chen: We have done some very primitive studies on wet web of glass and we approached it from both the dry and the wet side.

In the case of the tensile strength of the load, it reproduces very well from both ends. In other words, if we air dry a wet web and then remoisten it by a spray of water, it more or less approaches the same value. However, the caliper of the wet web does not follow the same line when we approach it from the dry end.

In other words, Mr. Gallay showed a minimum caliper at the maximum strength. When we dry the web and remoisten it, it does not return to the same low caliper and upon redrying again its seemed to approach a value higher than the original value.

Would you care to comment on that?

Lyne: Mr. Chen, we have not followed your procedure on glass fibers. We have, however, resoaked the pulp webs and worked backwards, redrying the soaked sheet up to dryness again, and in that case we have found that the stress and the general shape of the curve, is lower.

If this is the original shape of the curve (indicating), and we take this dried sheet or a similar sheet made in the same way and resoak it and dry it over again, we will come up underneath the first curve with a much longer plateau and we have not continued to dryness at this end (indicating) because we were only interested up to the 50% level. However, there are indications that we have lowered the total load-elongation curve and extended the length of this plateau (indicating), where we assumed the change in mechanisms occurred. No caliper measurements were made on these resoaked sheets.

Nissan: I would like to draw attention to the geometry of this situation.

A study of this has been done in great detail in another field. If you take spheres and pack them together then you can calculate the geometry for all kinds of packing systems. Now, in these studies it was found that the most compact form with spheres of equal size is reached at something like 26 to 27% void fraction.

In other words, figure is independent of size. When you reach that value then the spheres are in their most compact form and if you want to push them over, that is, if you want to sheer them, then they have to pass over something like an energy barrier and you get what Reynolds called dilatency. These statements apply for spheres of equal size and they do not apply directly here.

However, I should imagine that for uniform cylinders of equal diameter there would be another figure. Now, for cylinders arranged at random again one would expect a figure which characterizes such systems.

Now, I am wondering whether these points of inflection that we are getting are not connected with some such mechanical geometrical schemes.

I do not know whether any work has been done on that and I would like to hear Mr. Gallay's comments.

Gallay: I hope that Mr. Nissan is not suggesting that we attempt calculations on packing considerations with fibers, which is quite a different story than with spheres. However, his suggestion in that respect is extremely interesting.

Now, there are several criteria for dilatency. One of them is that you must have a minimum of adhesive force among the particles in the system because, generally speaking, a small amount of adhesion will destroy most if not all of the dilatency which would otherwise occur. Therefore, there is a possibility, on this basis, that dilatency would not be an operative factor in the explanation of these phenomena which we have observed.

Dilatency is usually measured on relative spherical particles because there you get the greatest dilatency. A higher axis ratio than one usually reduces the amount of the dilatency effect. However, dilatency has been measured and there is a figure in the literature for various dispersed particles of very high axis ratio.

However, it might still be interesting to see at what solids contents such systems show dilatency, if any, in comparison with the solids contents where we obtained some of these discontinuities.

Moderator Stamm: I am afraid that we could keep right

on going on this one subject for the rest of the afternoon but then we do have some other papers to discuss. I would like to turn now to the paper of Mr. Nissan.

SCHELHORN: From the interest already shown in this paper we can see that it is both fundamental and very practical at the same time. I don't have to tell you, for you are all dealing with the problem of water removal from the wet web all the time, that a few per cent one way or the other is a difference between successful or non-successful operation of the papermaking process.

Now, Mr. Nissan's paper as written, and not entirely as presented, was divided into roughly three equal parts.

The first concerned the construction and the preparation of the felts: the raw materials, the manufacturing methods, the finishing methods, and the properties of the felts. He then considered the function and the operation of the felt in the wet pressing operation and, finally, he considered the effect of the felt in the drying of the paper.

Now then, I would like to point out a few things about each of these.

As one who quite frequently confronts the manufacturers of paper machine felts, I should like to ask Mr. Nissan if there is anything, any additive, any special treatment, which can be given to the finished felt which will affect materially the ability of the felt to move water?

Second, since all felt manufacturers at one time or another are working with synthetic fibers, and, if you have studied Mr. Nissan's paper, he has very clearly shown that the submolecular configuration, the fibers, and everything in wool felts are almost ideal for our requirements.

What, then, are the felt manufacturers looking for in synthetic felts?

How can we improve on the wool in felts?

Going to the press section, the practical papermaker has always believed that he could influence the water removal on the presses. He thought he could do this by varying the nip-pressure, by varying the plastometer of the rolls to vary the width of the actual nip; and he thought that he could somewhat affect the water removal by the geometry of the press—the position of the top roll; the position of the suction box in the roll; how the paper approaches the nip; whether it comes in from the top through the air space; or whether it is riding on the felt.

Now, since Mr. Nissan speaks of the effect of the water removal by springback, I would like to ask him just how important this effect is in the over-all picture. The equilibrium conditions which must be present between the paper and the felt are not an instantaneous proposition.

I still believe that the nip length and the condition of the felt, which is dependent on the geometry of the press, are important.

You are all familiar with the trend in the industry to increase nip pressures. It seems that every year the pressures are a little bit higher. Now, with presses being placed in a drier section, we are working in ranges of 500 lb. per in. nip width and this poses the question of whether we have an ultimate limitation in reaching a point where the felt will no longer have elastic springback; whether we will reach a yield point so that the felt will not come back and remove water, as Mr. Nissan has presented.

Finally, Mr. Nissan has very clearly pointed out that on the wire we have a three-phase system: air, water, and stock. Surely, since we had so much trouble getting rid of the air on the wire, it hasn't disappeared when it gets into the press section.

I would like to ask Mr. Nissan, then, what happens to the air which is in the web? And how does it affect the over-all pressing?

He mentions in his paper that one of the functions of the felt is that the inter-facial tensions are to prevent the reentry of the air. How, then, does the air in the nip itself react in the over-all picture of wet pressing?

We now come to the very interesting, and I believe somewhat controversial operation of the felt in the drying section. I must agree that the felt plays a major part in the early part of the drying section. It is only in this way that we can explain the phenomena which you have all seen, that with the drier temperature low, the felt temperature low, the paper temperature low, and the air temperature low, we still can dry paper. The water must go somewhere.

The important part in his proposal here is that he regards the mechanism as operating by an air film which is expanded and forces the water into the felt. The limiting condition as he describes it is the entry of the water into the capillaries; or, it is an orifice condition.

Now, this is contrary to the statements made by Montgomery, who has expressed opinions that water is removed by the felt, but he says that it is a capillary action.

Concerning this air film, I know there is an air film at the in-running nip of the drier. I have always thought it was an enemy rather than something that was helping me get the water into the felt. You would expect the phenomenon of the increased drying on the Yankee drier, is caused by the absence of the air film which we have in a normal drying section.

NISSAN: There are seven different questions, and I hope some of the members of the audience will be able to supply the answers to them.

First—the treatment of finished felts to change the springback. Well, there are many treatments being tried. They haven't yet been applied to felts. For instance, a great deal is being done in polymerizing materials inside the wool fiber to change its characteristics, to make it non-shrinking, for instance; to strengthen it; to increase its bonds; and generally speaking, to change the chemistry of the bond. The work is an outcome of the general chemistry of wool, and of that most important process, the permanent waving of our ladies' hair.

This work, as I said, is recent and as you know, there is always a lag between the scientific findings in the laboratories and the application in industry; but a great deal is being done.

There are other treatments for felts, of course, from other points of view. Today I have, you remember, confined myself to water removal; but, of course, felts are being treated for antibacterial effects, and various other things.

If I may go to the second problem—synthetic fibers in felts for wet-ends.

A great deal of interest is being shown in that. Nylon has been tried; and as you know the felts are on the market. The strange thing about it is that it is found there is an upper limit to the amount of nylon you can put in, and it is mostly being put, into the weft. You may have other information in the States different from this. I would like to know.

Attempts have been made recently on an all-nylon felt; and the trouble there is that while it lasts very long, that you can't use it for as long as it lasts because nylon has not so much recovery as the wool fiber. In water, under certain acid conditions, wool fiber will recover from very large strains.

Nylon felts are being processed on the surface. They are using there, for instance, a specially crimped nylon. There is a new type of textured nylon yarn; it hasn't, of course, reached the felt area. It is still just being marketed as an experimental product. They announced it just recently, the textured nylon yarn—where loops are being put at intervals along the yarn of nylon. These loops tend to increase the bulkiness of the yarn, and to give it that springiness. You have here a "structural" property which supplies the deficiency, if you like, of the basic fiber.

I have here with me a copy of an abstract of an I.C.I. patent, in which felts of Terylene yarn or part Terylene yarn, that is the British name for Dacron, have been patented: and there, again, with what results I don't know. It has not been tried sufficiently. But clearly there is a very great interest because the life of the felt may be increased.

The essential point, of course, is that we want a useful life, because there is no greater advantage if you have to put away the felt, because it cuts the paper because of compression although it looks perfectly new.

Three—nip pressure versus plastometer versus geometry of the press; and do we get equilibrium?

Frankly, it is a field which I did not want to enter, not because of any reluctance or modesty—simply because I don't know much about it. I hope some of the audience will contribute to this.

The question deals with the mechanism of pressing water out by other than felt characteristics.

Clearly there is the question of how much water can you get? I mentioned that the absolute amount of water has to be reduced to a minimum in the felt, and the sheet before it springs back; and that I think must be affected by the geometry, by the surface characteristics, the plastometer reading of the surface of the roll and by the approach angle, and the rest of it. I do not have any factual observations to make.

Now, fourthly, is there a limit to the pressure on the nip?

Well, of course the sheet we are dealing with will set a limit. If you press too hard, it will tend to flow sideways, and be a plastic weak sheet; and I should imagine that would be one limit.

Now with regard to the felt, I think that an answer will be dangerous. There may be a limit to the felts as they are today; but all papermakers and all engineers and all chemists have, over the years, found out this: that when a demand is made, first the supplier of the particular material keeps on improving it. Then a time comes when the manufacturer changes something radically, and then you enter another field.

So, to say now there is a limit with felt constructions as they are now does not mean that, of course, under more severe demands the felt structure itself would not change. This would raise the limit.

We must remember that felt is not merely affected by the nature of the fiber, as I was trying to explain, too, in the paper. It goes from all methods to the methods you use when you spin it into a yarn—whether you will get a soft, bulky yarn or a hard and strong yarn—to the way, finally, you arrange these yarns relative to each other in weaving and finally by the way you finish it.

For instance, you get a different compressability value, and different characteristics entirely if you use thick warps with thin wefts; or, if you use balanced yarns that is, both of the same diameters and nature.

So, there are so many factors that I feel to generalize about the future is dangerous.

Air in the web, and how will that interfere with pressing?

I think the air must be there. It is both in the web and in the felt, and I think that the air will expand. Expanding, it will destroy part of the propulsive forces.

Whether there are other factors I do not know; but I would expect, that if the water is completely without air, there would be less tendency for this destruction of the propulsive forces. Next Montgomery says it is a capillary action. I have read Montgomery and I think that it is true; but I am not sure that he has specifically said that the flow follows Poiseille's law, or whether he is talking about flow *into* capillaries. I am not sure. I have had enough on my hands without having to pick a quarrel with Montgomery who knows far more about these things than I do.

Finally, the air film.

Of course, we do tend to try and simplify matters, and this world is not simple.

The air film has tremendous and profound effects on the heat transfer coefficient. A water film on a steam cylinder, has very much higher coefficients of heat transfer than a web of paper.

People have given data varying by several hundred per cent from each other, but none of them are less than about 200 B.t.u. per hr. per sq. ft. per °F. You don't get those figures with paper on multicylinder machines, and probably the chief reason there is that you have a system where you can't get that perfect contact that a water film makes with a cylinder.

When you go to a Yankee machine, you do try to get rid of that air film completely, and therefore the heat transfer is so much more, and the rate of evaporation so much higher, I think a ratio of about three to five times of what you get under similar conditions on a multimachine.

Now, if I have given the impression that I know all these answers, and have them pat, I apologize, because I don't; and I am hoping that others will comment on them—for one thing, to find out if they are correct.

WHITNEY: I should like to comment briefly on that portion of his paper which deals with felts in the drier and say, first of all, that I quite agree with him that the felts do exert a great effect on water removal in the drier.

Possibly one reason for this feeling is that I was one of those co-authors of the Sherwood paper to which Mr. Nissan referred, and that was the first contact that I had with this problem. I might mention that the other co-author, Mr. Gardner, is also here in the room, and possibly he would care to comment.

Partly as a result of that early work which was conducted, as Mr. Nissan pointed out, on slow bond machines, and partly because we think this is an interesting and important problem, we have continued our studies of drying here at the Institute, and I am afraid that what I can say will perhaps muddy the water more than clear it, but sometimes that is preliminary to some clarification.

This work has not been published partly for the reason that it has been piecemeal and has consisted mostly of isolated bits here and there.

We were particularly interested this morning in that portion of Mr. Nissan's paper which dealt with the air film which certainly must be carried in between the sheet and the drier and with the postulation that because of thermal expansion the air in the film, must either expand or must develop a pressure. That assumes, it seems to me, that the sheet is completely blocked off. That is, one does not build up a pressure unless he has a closed system.

Possibly I am reading words into Mr. Nissan's paper which he didn't mean to be there and therefore he can correct me. However, that implies that the sheet is completely water filled. On the contrary, we believe that in many cases, there is an inter-connected capillary system filled with air.

We have done some work which is not conclusive. However, in our mind, this work throws a little doubt on the theory of expulsion of the water by expansion of the air. There is other work, however, which has been done here and in other places with respect to the mechanism of movement of water in a sheet during drying.

Now, I think also that the remarks which Mr. Nissan made would indicate the movement of the liquid water is from the hot surface to the felt. I was a bit shocked some years ago to learn that liquid water moves the other way—that it moves *toward* the hot surface. We have demonstrated this here and I think we can say it quite factually. I should point out that the work was not original here. I mean by this that the observation was not first made here. I believe that it was first made in England by Preston and Chen* with respect to textile fibers and sheets made from textiles. Through our experiments we have shown that the movement of liquid water is at least in many cases, toward the hot surface. It may not be in all cases but in many cases it is.

This forced us to speculation which has already paralleled in some respect that which Mr. Nissan has told us about, and the best that we have been able to do is to postulate the type of mechanism which came out second best in Mr. Nissan's discussion, one of evaporation and condensation.

We think that at least a good portion of the mechanism of water removal during drying is one of movement of liquid

* Preston J. M., and Chen, *J. Soc. Dyers and Col.* 64: 60 (1948).

water *to* the hot surface, evaporation of the liquid *at* the hot surface to form water vapor, which then moves out into the sheet and it may condense before it goes out through the sheet. It may, in the last stages of drying, move as water vapor through the sheet and into the felt and condense there, and it may conceivably move through the sheet and the felt in the vapor form and be dissipated.

We agree with Mr. Nissan that felts should be designed and and made with consideration given to the water removal characteristics. We don't know, but we think that better felts might be made from that standpoint. I think that perhaps it might not be too radical to feel that some day in the future paper machine driers might look and act quite differently from those which we have today.

We would very much appreciate any comments which Mr. Nissan cares to make.

NISSAN: I don't think that I can make much comment. Mr. Whitney made some factual observations and I hope that they will be published because there is a real lack of information on this very interesting subject.

If this paper stimulates both here and elsewhere a searching of files and of hearts to get information and publish them, then it will have served a very good purpose.

I have very little to say. The ideas that were put forward as speculation, were to explain the information available—to explain the facts as reported by Attwood and Smith.

Now, you do not build—you do not call a hypothesis a theory on the basis of one explanation and, as I said this morning, I think the mere fact that a straight line is obtained by the half power load, that is obtained on the basis of a hypothesis, this must not induce you to accept the hypothesis as the only possible hypothesis and therefore, we must leave our minds open.

On the other hand, it does explain the hypothesis insofar as one can test it and, frankly, if the more interesting mechanism of the double flow backwards and forwards under the conditions as put forth is substantiated by facts, well, that is the answer to it. Then there is nothing more to it than to ask them how to make it apply in practice.

As I said before, I hope that the information that was presented here today can be published so that we can all study it.

STEENBERG: As a matter of fact, those things about the drying are published. The first publication was in 1890. I am sorry that I cannot think of the German name of the place where it was published.

Now, he treated the case of—I don't know what you would call it but we call it flowering. When you have bricks, you get salt coming out on the hot side. It comes out to the heated side. He made some beautiful experiments to prove that you had a transport of liquid water in one way and evaporation from the other side, which simply washed all of the salts out to the hot surface.

He treated this thing in a very nice way and I think that all of the basic information required is found in that paper. I will be happy to submit the title for the printed discussion when I get home.

Then, of course, the second paper is one which was printed in England by Preston and Chen. That was done shortly after the war. They also have some beautiful experiments on this.

It isn't experimental observation that you cannot increase your capacity on a paper machine by increasing your felt driers, because the heat can only go one way and that is apart from the convex. It has to go to evaporate the water and the way that you introduce your heat it doesn't matter. You see, if you have the water evaporating from the top side it will condense in the felt and, of course, you get back your heat of condensation. Then you can dry out your felt by putting in more heat.

This thing is, of course, nicely explained by this double transmission system and it is a pity that felt driers are too often built smaller than the paper driers. They should certainly be of the same size as the paper drier and you should provide space for something extra because it is just building cost. You should put up an extra drier instead of elongating your machines, changing press sections and so on. I think that this double number system is definitely proved.

I was, however, rather surprised about the idea that in paper drying you could prove there was a continuous system of capillaries. It would be nice to have a description of how you dry glassine under those conditions.

NISSAN: I was referring to Mr. Whitney's results; these could not have been published in 1890 I think that we have to be careful of one little thing and that is too much analogy. The case of water movement I think should be discussed in each case as it is affected by the conditions prevailing in that case and not by others.

You in America probably would not see what I am going to tell you about toasting bread because your toastmaker people have given you those automatic things—you never see what happens to the toast. The bread is just put in there and it comes out toasted and if it didn't then you push it in again. If it is burnt then you change to another toaster.

However, we in England have more primitive toasting methods and it is an observation which you can demonstrate to yourself. If you toast bread you will find that the movement is going from the heated side to the other. Now that doesn't mean that because of this observation, my hypothesis is correct anymore than that other observations with bricks disprove the hypothesis since the thermal and aero-and hydrodynamic conditions are so different.

Now, there is another thing and that is this business of evaporation and of backward and forward movement. You have to remember that you are getting four times the amount of water removed next to the felt than in the free air and that the colder the cylinder is, the more this effect. I think an evaporation mechanism is more difficult to explain quantitatively than liquid movement.

As a matter of fact, if you want to refer to 1890, I think you will find most of what we are dealing with has been dealt with perhaps even in earlier times. I am sure that you will find that often and I have no doubt of that. There is always a reference to something which has been studied scientifically, but what is important, is that we apply it to the problems of paper. There is always the case that there is more in scientific literature than in technological literature.

HUGHSTON: First an observation. We have run moisture tests on running felts on high speed machines, six machines, and on the first, top and bottom felts, the results were highly surprising to us.

The maximum moisture or wet basis in the first low felt for example was not much over 7% and the minimum was around 2½% and the average was about 4½%.

Now, my question, is this. Does this seriously conflict with Mr. Nissan's theory of liquid transmission into the felt?

Now, I would like to further comment that Mr. Whitney's reverse theory could coincide with our findings in that if the vapor was passing through the paper into the felt and right out through the felt that it would act for or account for our very low moisture figures and it would also account for the fact that you can dry paper with felt.

NISSAN: The answer depends purely on the other data which are necessary for forming a conclusion. Do you find in your determination that in fact you remove a lot of water from the web on the first few cylinders in contact with the felt as compared with the air or do you find that you do not? Now, the whole point was that these earlier experiments have shown that you do. According to the work of Attwood and Smith and others, they found that on the early cylinders that they did remove a lot of water from the web. The purpose of the paper was to explain this finding and also why in other machines, this mechanism does not apply.

Now, it would be very interesting to find out whether on these high speed determinations whether, in fact, water leaves the web in contact with the felt in the ratio of three to four times as much as goes into the free air or doesn't it? The answer depends on these other facts.

HUGHSTON: Part of my answer is to the effect that one measurement in one of our mills was that a third of the moisture leaving the paper came out through the end of the drier. I don't know that I can add much to that except that I wasn't claiming that this conflicted with Mr. Nissan's theory.

RANCE: Personally, I should like to say that I can see nothing whatever incompatible between these two theories. As far as I can see, they can exist simultaneously or successively.

Now, I have a question. Two other speakers have mentioned the case of very wet beaten paper, where there is virtually no air and where, of course, the structure is a fine structure—it is a very wet structure through which the water cannot flow very easily.

Would you, Mr. Nissan, care to speculate on the possible change of pattern between these two effects in the case of a web made from very wet beaten stock?

NISSAN: I do not feel adverse to speculation provided that it serves a useful purpose and by that I mean that it sets us on a critical experiment or some critical calculation to see where to go next.

I believe that is the main use for speculation and provided that we can always go back and check our speculation and throw them overboard as soon as we find that they are wrong. I do not have the slighest worry about that.

However, I believe, from this discussion, that we are generalizing too much. There are different things that occur at different times. They may even occur at the same time giving complex results.

Thus a wet sheet may actually present a better field for the movement of a layer of water provided other things are in favor.

We always forget one big element in the paper machine, and that is the papermaker. He is a very big element in that machine; and when he finds he is having bad conditions, he changes the condition of the machine to give him what he wants.

Therefore, we draw, probably, conclusions which need not apply to the physics and chemistry of the operation; and frankly, that is why I am hesitant to make a generalization, because I can see all kinds of special conditions influencing each result of each machine.

Every papermaker knows that a dry woolen felt will take very little moisture out of the presses until you wet it out.

So, simply to say that a dry wool felt will take water is misleading.

But to say that a waterlogged felt will take more water than a dry felt is also misleading.

What is lacking is a set of factual quantitative data with the parameters given so that we can see the relative importance of mechanisms for each case in papermaking.

SCHELHORN: Here is a question from H. C. Martin, of the Brown Paper Mill Co.:

"If the water with the sheet contains a solute, wouldn't the accumulation of this solute in the felt give a measure of the amount of water transferred from the sheet to the felt in the liquid phase?"

NISSAN: I think that it is a possible method.

In that respect I was informed that certain cotton felts were reported to be deteriorating rather fast; and on examination it was found that the materials in the paper were responsible. It was as the result of discussing this hypothesis with a friend of mine in the felt business that I was given that information; but again, no quantitative information was given.

I can't give it to you as a proof of what I am saying, but simply as an indication that probably under certain circumstances it would be a way of measuring it, because there it was clearly a case that the solute, which was the active agent in deteriorating the felt, was found to be transferring with the water, and it was not therefore a case of water evaporating.

This agent—I think it was an acid, or something—I don't remember what it was—but this chemical was found to have penetrated right through the felt—and not at the surface.

On the other hand, this doesn't, of course, as every physicist knows, prove my theory, because you can have things diffusing without actual water movements. But that is all the evidence I have in that direction.

SCHELHORN: Here is a comment from Charles A. Shoudy, of the West Virginia Pulp & Paper Co.

"In your chart showing drier surface temperatures, there was a very sharp sawtooth graph. This indicates that the top drier surface temperature is quite different from the bottom surface temperatures, even through they are fed the same pressure steam.

"We have found this to be the case in some surface temperature phase studies we have made."

He asks to have you elaborate on it.

NISSAN: I am afraid there is a misunderstanding. The graph was the temperature of the sheet as it moved from cycle to cycle, and the sawtooth was the increase in the temperature in the sheet as it contacted the cylinder; went up to the end of phase 3, when it began to evaporate water, in the free air and got cold again.

It is not the temperature at the top and the bottom cylinders. But I fear it belongs to another lecture. That's why I couldn't elaborate on it.

Other questions answered after the meeting follows:

Mr. Nissan, you are no doubt aware of the recent work of Barkas and Hallan showing the "capillary suction" of pulp as a function of moisture content. Is it not true that the moisture content at any given suction value represents the limit to possible water removal by that suction or pressure?

For typical pulps, according to Barkas and Hallan, the equilibrium moisture content for 10 in. of water is over 500% even after correction for the decrease in surface tension due to higher sheet temperature. Thus if the pulp is below 500% moisture content on a drier drum the 10-in. water pressure could not cause water to be driven into the felt.

This does not mean that there can be no transfer of liquid water to the felt. It does seem to imply that the felt must be of such a nature and have such a moisture content that its capillary suction is greater than that of the wet web, if such a liquid flow occurs. This driving force would be likely to be much larger than the driving force due to the pressure of the heated, enclosed air film.

Your comments will be sincerely appreciated.

ARTHUR DRESHFIELD, JR.
Institute of Paper Chemistry

NISSAN: The problem posed by this question is, in my opinion, valid. The picture as presented by Barkas and Hallan and by Barkas and Christensen in their fascinating and exact work is, unfortunately, more complex than the question implies. Thus looking at a graph in a paper by the latter two authors I see that for an unbeaten pulp the moisture content, in grams per gram, at, say, 2 cm. Hg is about 7.5 on the first desorption curve, about 2.5 on the succeeding adsorption curve—the pulp having been subjected to a maximum of about 8.5 cm. Hg tension in between—and about 7 on the second desorption curve. In other words, the "equilibrium value" is greatly dependent on the mechanical history of the sample and particularly the maximum compression to which the pad is subjected. Thus no simple and general answer is possible; again, every case should be analyzed individually.

Machines with 6-ft. driers have a lower drying rate per

unit than 5-ft. ones. This would indicate that the last section of the contact area is not doing much work.

E. Cowan
Consulting Engineer

Nissan: According to theory and observation, both the over-all transfer of heat and water vapor decrease with each succeeding foot of length; thus the average decreases with length of a sheet around a drum or with the diameter of the drum for equal angles of wrap. There are other complicating factors peculiar to each machine.

How do you reconcile the high unit press pressures required in press sections with exceedingly low unit pressures you refer to in contact area on driers?

E. Cowan
Consulting Engineer

Nissan: The time of action in the two processes, the temperature and consequently the properties of the water, and the mechanism of pressure application are very different from each other in the two processes. Each, I believe, should be studied individually for maximum information. As I mentioned in connection with the heating of bricks in kilns, toasting bread, or heating textiles—analogies may be misleading as different mechanisms may be operating.

Re drier felt action and paper drying in the drier section Some years ago drying paper in a vacuum drier we observed the following which may tend to confirm or contradict some of the ideas expressed.

(1) Felt tension had to be increased to hold sheet to driers, may have been necessary due to absence of atmospheric pressure on both sides but we assumed it was due to vapor pressure between sheet and felt driers. What about this condition under standard drying conditions?

(2) Felt wetting became a limiting drier factor before designed speed attained. One drier top and bottom then by-pass by sheet and speed-up attained.

G. H. Kirby
Rolland Paper Co.

Nissan: (1) At 28 in. or better water vapor will provide a film resistance as air does at atmospheric pressure.

(2) These remarks are in line with those expressed in the paper.

We have added solutions of anionic, cationic, and non-ionic wetting agents at the couch presser roll. What is your explanation for the lack of favorable results in press section water removal?

G. D. Hughson
Canadian International Paper Co.

Nissan: I do not know the answer, but I may offer a tentative explanation. The dynamic surface tension of water starts with that of nearly pure water and attains the final equilibrium in the interface after a lapse of time. This time can be quite long in certain exceptional cases but more often it is a small fraction of a second. If the time of action taken by the water movement from web to felt is longer than the time taken for the surface tension to attain equilibrium, then it would be expected that water will behave as a low surface tension liquid. On the other hand, if this water transport time is shorter than it takes the surface-active agent to concentrate in the surface, then the water will behave as a high surface tension liquid. A study of these times in relation to each other may shed some light on the problem.

Moderator Stamm: Now, our next paper is the one by MacLaurin and Whalen; and Tongren, you have some remarks.

John C. Tongren (Hammermill Paper Co.): This paper by MacLaurin and Whalen is a factual report which suggests, in a limited way, that we might even have some stock preparation help from the paper machine. It would be fortunate if the paper machine could provide some help in that direction because sometimes the stock preparation people seem to slip up on that a bit.

If we would ask some machine tenders, they might hasten to admit that they had to add something to the stock on their machines which the stock preparation personnel had failed to include.

The presentation by MacLaurin and Whalen takes a simplified approach in using the unbleached fiber slurried in water. This is a good beginning.

In looking at this situation, some of us who are acquainted with systems with more components than merely fiber and water, would ask some questions, and we might turn to that a bit later.

In the beginning of the report MacLaurin refers to the pressings, and by a bit of calculation it appears we have a 5 point increase with 150 lb. per line-in. It would be nice to get that help when you are in need of it in meeting specifications.

Of course, these results obtained under laboratory conditions will have to be adjusted by some kind of a factor when we step out into the mill.

Now, moving toward his next step, where he goes from 3 in. diameter press rolls to 12 in.diameter press rolls, and takes his sheet speed from 5.7 up to 44 f.p.m., we like to extend that and say, what happens when we go to say 10 times that speed, or 440; or, even up to the practical speeds for many of you, say 1760 f.p.m?

I wish that Mr. MacLaurin would make some comment on what he might expect to happen strengthwise under those conditions.

There was another reference to the entering moisture in the press section being in the range of say 16 to 20%, and the moisture leaving the press section in the range of say 30% or more.

The data indicated that some of the bursting strength improvement falls in the range of 40 to 50% total solids, and that seems to be an area in which the conventional machines don't find themselves under most conditions.

One comment that was made by Mr. Schelhorn with regard to presses installed in drier sections, and here we might possibly get these higher line pressures, I just wonder if Mr. MacLaurin would comment on that —whether we might expect to get our line pressures up to the point where we might get some gain, strengthwise.

We made some reference to this two-component system of fiber and water. We also referred to systems where we had additional components such as fillers, sizing materials, or other additives such as deflocculating agents. They undoubtedly have some effect that we should not overlook.

I think there are some other factors that we would all like to hear about—other characteristics of the sheet which might be affected. But we may have to let that go for the time being, and to hear what Mr. MacLaurin says on some of these questions which have been raised.

MacLaurin: The first question you raise, that our data dealt with essentially the two-component system; that is the simple fiber-water system, and there were no such things as fillers or other materials present. That is, of course, quite true; and admittedly and naturally data relating to the effects of wet-pressing, when more than two components are present, would be very interesting.

We haven't done any experimental work along that line, but perhaps later on, it may develop that some other people have. I don't know of any in the literature.

The second question that Mr. Tongren raised, or indicated he'd like some comment on was—here is some laboratory data,

at obviously very nearly static conditions, and the thing of interest from the papermaking point of view will be when we get up to dynamic conditions, where the rate and speeds are way beyond the kind of thing we were exploring, then what will happen?

Perhaps we could look at it this way. We were concerned with removing a certain amount of water by pressing, or compacting the sheet to a certain extent. Then we observed the final step, and that is the only kind of data we reported.

There is admittedly a tremendous area to be explored, which deals with the rate of removal of water from the wet sheets and with what you might call the rheology of the wet sheet, the rate of springback, and the rate of compression.

Our limited data merely say that if you achieve these things in the way of compactness, you should expect these results in the dry sheet. There is a whole area of study open involving breaks.

Mr. Tongren indicated that our data showed that the major improvements took place at solid content up in the range of 40 to 50%. I think we would say the data indicate that up to 40 to 50% solids content there is no change in rate; but at a solid content somewhere above the range, between 40 to 50%, the improvement significantly drops off.

The fifth point is the increment of change in sheet properties from 20 to 30% solid is about the same as from 30 to 40; and it begins to drop off greatly when you get to other regions.

There appears to be a limit to which you can compact a sheet in terms of gains in strength, and beyond that there is very little to be gained.

I understand that Mr. Limerick posed the question concerning the pressing of the sheet further up in the drier section—that is, at the breaker stack, or perhaps further along in the drier section.

We haven't any great amount of data in this area; but some very preliminary experiments led us to consider that if a pressing mechanism for removal of water—that is, an extrusion mechanism, is interrupted by an evaporation mechanism, that no further strength is gained as a result of extrusion. Now I say that very tentatively, and the data are very limited; but it does appear that if you interrupt and have an evaporation sequence between two expression sequences, the two expression sequences are not applicable; the first one only applies.

Moderator Stamm: Are there questions from the floor?

Ivarsson: Like Mr. MacLaurin, I have also been working in the third part of the self-same area that was pointed out by Mr. Nissan this afternoon, the stress-strain area.

In this area, we are usually working in this part of the section (indicating on blackboard); and in compression we are working in this third quarter; and if we turn this part of the diagram around, then we get this kind of diagram (indicating). We get the flow here, and we get the elongation here.

In the paper which I gave a week ago, at the American Chemical Society meeting in New York, I showed some data which extended this over the moisture range, down to almost dry fiber. I understand that MacLaurin's work has been around 30% dryness, or in that area.

If you study a piece of cellulose (drawing on blackboard), and compress the cellulose under load here, and we say we have compression this way (downward), then if we remove the load, we have, of course an even amount of springback (upward). I will call the compression C, and the springback is S. Now, this part of it refers to P—and we call that permanent set. You know what it is—it isn't actually permanent.

Now, if we study this compression in the first cycle, we notice that there is a considerable difference between this cycle and later cycles, which is known to all who work in this field.

If we study these conditions under a fourth cycle, then we know that the difference is due to sheet formation. Most of them are cancelled out, and we can study the compression, or decompression—the compression corrected for capillary action, and study it for moisture content.

And then if we say this is a hundred per cent, 1 part water per 1 part of dry cellulose, moisture content comes this way, then we notice there is a bend in this curve, and this area here is between 12 to 15% of moisture; and then the curve goes up until the moisture content is between 30 to 40%, and then it continues, of course, and goes upward slightly.

This actually seems to be the condition for all the various kinds of pulps I have studied—unbleached and bleached sulphite; unbleached and bleached kraft, and so on.

I would like to have some comments on his work. It is a very interesting work from a papermaking point of view, because we know, for example, in making paper we are working around 25% moisture content. And with some new, hot presses, we are probably working somewhere in this area (indicating).

But the question is, if we move this around in the paper machine, can we improve the result of the compression?

Actually, if you started an elastic modulus, you would find that it moves at the maximum in the same area. This is the Young's modulus of the cellulose in the content of that sheet.

Gallay: I have a few minor comments.

It was my understanding this morning that he (Mr. MacLaurin) would talk about two phases, and he intimated that air was not present. I find it very difficult to agree that air is not present. I find it difficult to conceive of his pushing out all the air in the sheet under the nip; and of the fraction of the air that is pushed out of that nip, a great deal of it will undoubtedly re-appear when the pressure is released.

Mr. MacLaurin found that wet-pressing and refining have approximately the same effect on the dry sheet properties. This is gratifying since we showed this morning exactly the same thing in the wet web region rather than in the drier region.

Now, with regard to his very interesting findings on a number of passes on a nip versus a single pass through a nip at high pressure. You will recall that many passes at low pressure were less effective, than a single pass at high pressure.

We would rather expect this in view of our concept of the ability of air water interfaces to accommodate themselves more readily under a series of low pressures and therefore keep the system more nearly the same as it was before. However, under a single stage which involves a high pressure, we would expect such a major distortion of the air-water interfaces that the release of the water would be more readily effected.

As my last comment I would like to point out Mr. MacLaurin has said nothing about the very interesting possibility of orientation of fibers in the nip as a result of the countercurrent flow of the water in that nip.

Sproul: I would like to know what the ultimate density in terms of pounds per cubic centimeters could be obtained by wet-pressing and what the effect is of the thickness of the pad?

MacLaurin: I think that this is a very difficult question to answer. It would depend on the definition of ultimate.

Clark: This interesting subject by Mr. MacLaurin can be divided into two parts: one is the effect of raising the density of the sheet and the other on the means of obtaining it.

He mentioned Doughty's classical work of tensile strength as against density. Doughty found a completely straight line which I have confirmed and others have done the same.

He also found another effect that if he beat that pulp ever so lightly, starting from a point down here (indicating) he got a parallel curve situated above the other (indicating).

He did not describe at the time why there was an increase through beating. From some work that was done later I feel sure that the increase was due to fibrillation.

I think that we can write down, and I have repeatedly confirmed this and particularly over the past few years—that we can write down and accept as a law and with a minimum of speculation certain facts namely that burst and tensile vary directly with density and tear varies inversely with the density of standard test sheets.

There is one more thing before I sit down and that is that this question about fiber lengths affecting density is the bunk. Fiber length does not affect density.

Doughty's experiments in seperating these fractions out, as were pointed out today, were due to the fineness of the individual particles.

We know, if we look into the microscope that the short particles form a glass fiber and that they are very much finer than the long ones and by very arduous work, we have found that some of those things are not apparent.

Moderator Stamm: The last paper was by Burkhard and Wrist and I am going to ask Mr. Davis to discuss this paper.

Davis: Mr. Burkhard and Mr. Wrist have added to the discussion which we have had on Tuesday, where the plastic flow of dilute suspension was mentioned and to the discussion which we had today, where we have had the plastic flow of paper both wet and dry. In this paper, we have heard of the plastic flow of the flow box or at least a slice. That, of course, was incidental to this description of improvements in methods for measuring the variability of basis weight of finished paper.

They started out with the methods which many of us, I think, have used—of cutting the sheet of paper up into many little pieces, starting first with single strips and discovering that not always did successive strips give the same result and then going from that to cutting up larger areas of paper into many little pieces and, by gravimetric methods determining the basis weight. Then they went to modern methods and substituted a beta gage. We have here the first application that has been mentioned in these meetings of the use of nuclear discoveries.

Now, their analysis does give one a set of numbers which have some meaning and a numerical estimate of the degree of significance of the results attained.

Finally, in the last part of their paper, they describe the use of time series analysis, correlograms, which are methods which they have used and methods which we in the paper business are going to have to learn. I predict that we will find them quite valuable.

The results of their work is demonstrated by the table on the board back here. They show that there are large differences in performance between paper machines. That is something that we all know. What we did not know, in most cases, was really how different they were.

In the past we have had no numerical measure. Burkhard and Wrist have contributed that.

They have also been able to show some of the differences in basis weight variability which arise from conditions of machine speeds and other machine differences.

I am sure that if only we would ask that we could start a lengthy discussion on why certain of these machines were so much better than others in their performance—why it is that machine speeds seem to be limited by breaks at limiting variances as measured with this particular size of basis weight sample.

I think that it would be pertinent if one or the other of the authors would tell us a little bit about how they handled the data. Most of us who have taken such data have wished that we could get more. However, when you start to use a recording gage you find that you are faced with an infinity of data and as a result you have to pick and choose among the pieces of infinity.

This seems to be something very good but then it also seems to be a very laborious job to take off some 2400 numbers per experiment and then manipulate the data thereafter.

I am sure that they have at least a few short cuts that they have used in the past and something that might help us.

Wrist: I will take the last question first.

On the very first test we took the readings at 120 points across the graph and then we did all manipulations of the numbers on a desk calculator. However, it took about a day to do the work for the one test and then we made the first check and found a mistake. That meant that we had to go through the whole thing again to find out where the mistake was.

We quickly realized that unless we got some automatic method that it was pointless in carrying on with the work.

Now, we were fortunate in having in our accounting department some IBM equipment and for all subsequent experiments we have made use of the punch card system for evaluating the results.

The equipment that we have does not allow us to multiply easily. Of course, there is IBM equipment which allows this but ours doesn't and, therefore, for obtaining the squares, we have used a dodge which might be useful.

All of the numbers that we take vary from zero to a hundred and therefore we could prepare a standard set of cards with the numbers from zero to a hundred and also punch the squares of those numbers on to the cards. Then, when we have put our original data on to the IBM cards, we can sort them according to value and then unto all numbers of one value we could punch the square of that number from the master card. All of that is done automatically in a collator.

Now, having the squares of the numbers on the same card as the original number, we can do the addition by rows, by columns, by position across the machine.

With regard to the correlograms, the reason that we haven't done much more work on that is the simple one that I stated—that we cannot readily multiply on our equipment and until we can work out a method we do not propose to do this work.

Davis: I would be interested in how frequently you find this method useful and in what results you are most interested?

Wrist: There have been two particular applications that we have found useful ourselves.

One was that we were particularly interested in knowing how one of our particular machines was going to behave at high speeds—whether we could predict from the behavior in the normal operating range what the likely variation would then be outside of that range.

If you will recall the graph where we plotted the basis weight variation against the speed, it doesn't give much indication of trend. However, we did find that by using the analysis variance and separating the variations into the three component positions of direction at random, we were able to pick out definite trends in those components and then by combining the trends we were able to obtain a trend line for the total basis weight variation.

The other application was one which I am afraid we can't elaborate too far in this discussion, and that was in connection with headbox design.

We wanted to find out how far headbox design could influence basis weight variation. For that reason we surveyed as wide a field of headbox design as we could find to see how the components varied.

You will notice from Table I in our paper that there is quite a large variation between machines in a particular speed group. Some have very large random variations; others have very small. Some have large cross variations; others have small. And it is in the interpretation of these components in terms of the design of the headbox that we found some use for the method.

Unfortunately, the samples we obtained from the other paper companies were obtained on the understanding that we would only identify the machines by numbers. Therefore, I am afraid I can't identify the letters with any particular headbox.

We did think, however, that the method as we have described it might be useful to other people working in the field, so that they can apply their own headboxes.

SHOUMATOFF: I sincerely appreciate the work that Burkhard and Wrist have done; and also the interesting comparison that Mr. Walker gave us on work done by Messrs. Mardon and Gavelin.†

I happen to be right in the middle of a similar problem, and am grateful for the helpful example provided by this paper.

We have a beta meter on which we have taken sheet profiles, in different mills. We have already been able to get definite improvement in the profiles by giving the charts to the machine tenders regularly.

In one mill, as an experiment, instead of the conventional profile we ran some parallel strips through the beta meter in the machine direction. From visual inspection of these charts, it appears that there was a dominant cycling at about 400 r.p.m. which was equivalent to a wavelength of about 2 ft. The machine was making a heavy grade of paper. There was a very definite pulsation, which could be felt around the headbox and the piping under it, which seemed to be correlated with the vacuum pumps and could be causing a pressure wave at the slice. Here, I am just speculating. We haven't proved this.

In connection with the analysis of these data, I hope to determine the cycles with a numerical method. Here we have seen that in most of the work that Burkhard and Wrist's paper covers, they use the analysis of variance. When they undertook the time series analysis, they used another method, which I understand is the accepted method for time series analysis.

It has occurred to me that one may get desired results—by using the analysis of variance for the time series analysis, which I believe is rather unorthodox. The principle involved is simply a matter of sorting the positive and negative phases of each wavelength for any given frequency into two sets, totaling each one, and calculating variance. This can be done for every consecutive frequency from the smallest, where the wavelength would be equal to two readings, up to the full length of the sample.

I might mention here that actually, although these traces seem to be continuous, in a practical sense they are not, because the scanning covers a finite area, which determines how closely one may determine meaningful adjacent readings. In this case it looks like about 1 in. apart on the sample.

The analysis of variance—I think I have indicated how it would be done—would have several advantages over the correlogram periodiogram method.

First of all, it would yield a complete frequency spectrum without using trigonometric functions. Furthermore, from the residual variance, and the variance ratio we would have

† For which, see end of third day's discussion.

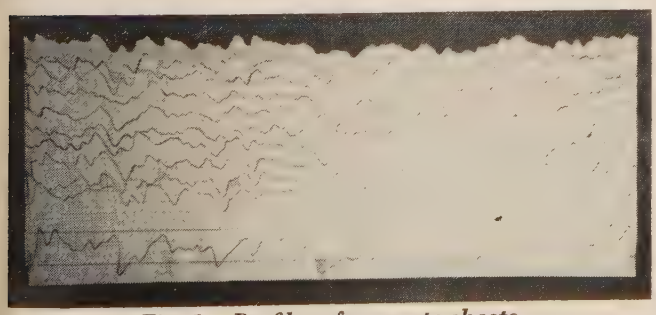

Fig. 1. Profiles of separate sheets

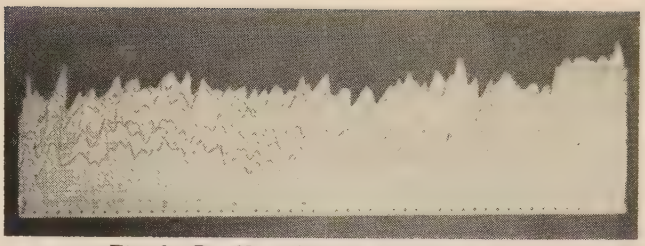

Fig. 2 Profiles of six consecutive reels

the equivalent of what the electronic engineers call the "signal to noise ratio."

Now from the "signal" we would immediately try to find external sources of disturbance, such as the vibration that I mentioned, provided they are statistically significant. The noise portion, or the random part, would represent the hydraulic turbulence. And we could study each of those independently and try to reduce each one.

Now, about the computation—I had some experience in connection with some TAPPI committee work on some very extensive analysis of variance which was done for us by a

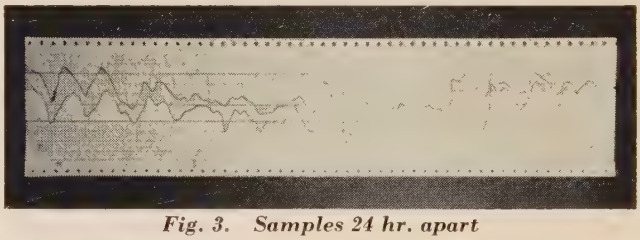

Fig. 3. Samples 24 hr. apart

research organization, using electronic computers. They reported that these digital computers are highly subject to "neuroses" and "psychoses," and they had to check them constantly with the desk calculator. So, I am quite staggered by what all this involves.

I am hoping that some simple method of cycle determination will be suggested. If anybody knows of one, I would certainly like to hear about it. Possibly with proper equipment and electrical methods similar to those Mr. Mason used to study formation, which is really quite an analogous problem, something might be done. Eventually we may have tuned oscillators and cathode ray oscilloscopes in our ma-

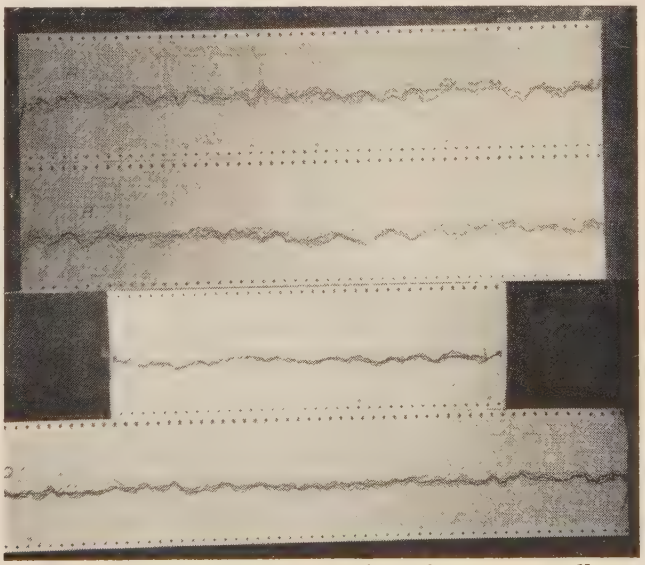

Fig. 4. Consecutive profiles from four paper mills

chine room control labs, and test the cycles and their amplitudes as a routine matter.

Wrist: I hope we haven't given in the paper the impression that the correlogram is the ultimate method of analyzing variations in the machine direction. This is the one thing which you can do fairly simply with the desk calculator, for an analysis of the data. The most information is obtained from a fourier analysis of the data in the form of the perosdogram. This is a much more lengthy computation, and for that reason we have not yet done it. When that is done, you will be able to express the variation due to particular frequencies in the form of a signal to random noise relationship.

Also, the particular shape of the audiograms will tell you whether the frequency peak is a very sharp one and therefore caused by something mechanical, such as a pump rotating at a fixed rate, or a roll in the headbox; or, it may be that you get a very broad peak in your frequency diagram, which means that it is associated with frequencies of the white water system.

And there are all sorts of possibilities which will come out.

We felt that until we could find an economical way of computing the data we had to leave it where we did.

Van der Meer: The basis weight tests have also been carried on in the five Van Gelder Zonen mills and a German

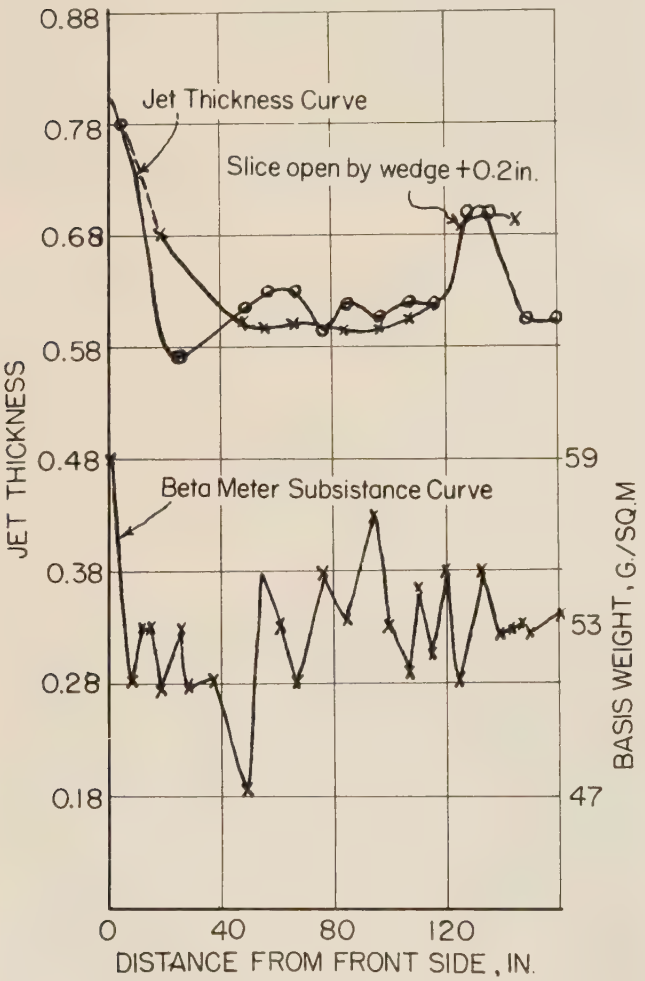

Fig. 5. Variation in jet thickness A/L-M/L

paper machine factory. Arrangements were made before the beginning of the program between J. Mardon and the two European mills to insure the use of identical measuring devices.

Many of the sources of the mentioned weight differences will be found between the holey roll and first table roll, what we have missed in this symposium. These result in part from the crossing of the thicker flows coming from certain places where the slice is more opened. These places flow out sideward, and this velocity changes with the square root of the water depth. When the dewatering possibility changes, the crossing changes and so does your weight curve. Therefore

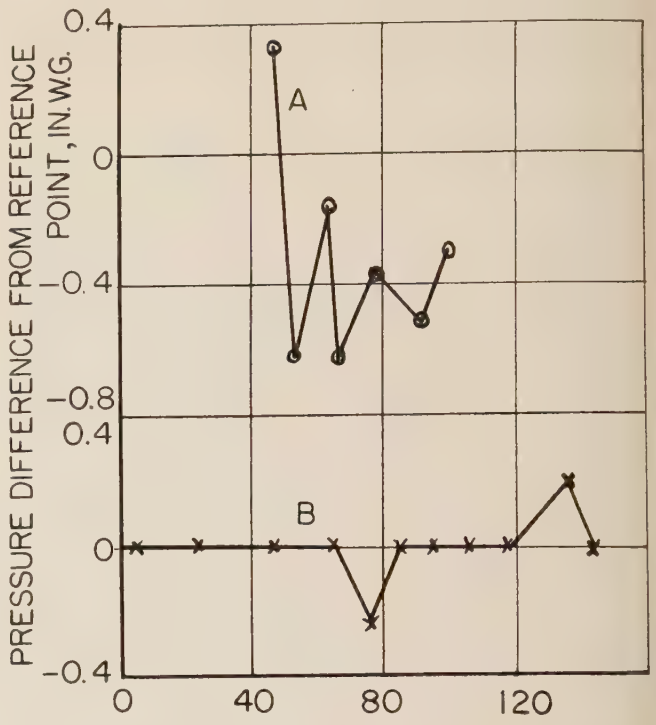

Fig. 6. Variation of jet pressure across M/L

A—section of plot for M/L with uneven conditions. B—M/L with even conditions.

it's necessary that the slice lip can be moved very easily, not with 0.05 in. but by 0.005 in. per turn. And no big distortions, as the plate will bend through them also between the next adjustments and a system of cross streams is the result.

Another case is that with the long slice, only a flat slice plate can bend over its whole length till its fixing point. A curved lip bends only over a short distance (think of a half pipe, making a buckle in one side you will see nothing of it at the other).

As a result, the opening angle of the slice lips changes, and so the bissectric of that angle which is the jet direction.

When the jet comes on the wire at a certain place at a later point, the stock will flow from that point to the sides and a thinner place is the result.

Another thing is that top and underplate must have over the whole width the same shape and that the underplate must have a constant height above the breast roll.

Also, the corner of the sliceplate must be straight and sharp otherwise the jet does not know where to leave the plates.

O. J. Walker (Anglo-Canadian Pulp & Paper Mills, Ltd): I should like to supplement the work of Burkhard and Wrist with a very brief description of somewhat similar work done by G. Gavelin of Northeastern Paper Products. He used much the same equipment but the manner of collection and presentation of his data is somewhat different.

Figure 1 shows the variation in substance of newsprint in the cross machine direction taken at intervals of 10 ft. in the machine direction. You will observe that the gross pattern persists, but coincidence is far from perfect due to the machine direction fluctuations gone into so thoroughly by Burkhard and Wrist. At the bottom of the figure is shown the

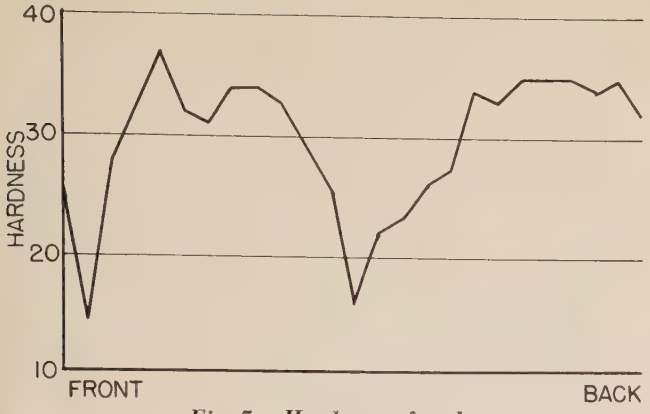

Fig. 7. Hardness of reel

average variation in substance determined by passing all sheets through the meter at one time.

As described in the preceding paper the average configuration is quite stable over considerable periods of time.

Figure 2 shows traverses of successive reels and Fig. 3, reels taken 24 hr. apart. Figure 4 shows traces of individual sheets superimposed on one another. This was done by rolling back the chart of the beta ray gage to the point of origin. It can be seen as in Fig. 1 that the overall pattern is repetitive but perfect coincidence is marred by the short term fluctuations. This pictorial method enables one to compare different machines or one machine after alteration. For instance from these traces performance levels can be judged by eye.

In collaboration with Mardon, an attempt was made to correlate slice opening under load determined by the pitot tube method to basis weight. Contrary to the findings of Burkhard and Wrist, no relationship can be seen (Fig. 5). It would appear that in this example the irregularities are the result of adjustments of the slice lip to compensate for hydraulic conditions produced in the gravity flow structure

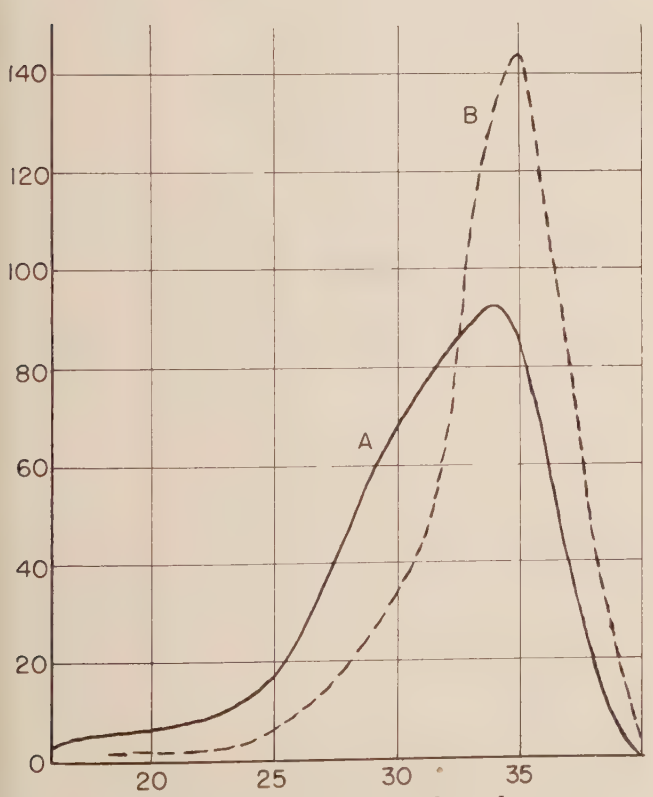

Fig. 8. Hardness distribution on wide and narrow machines

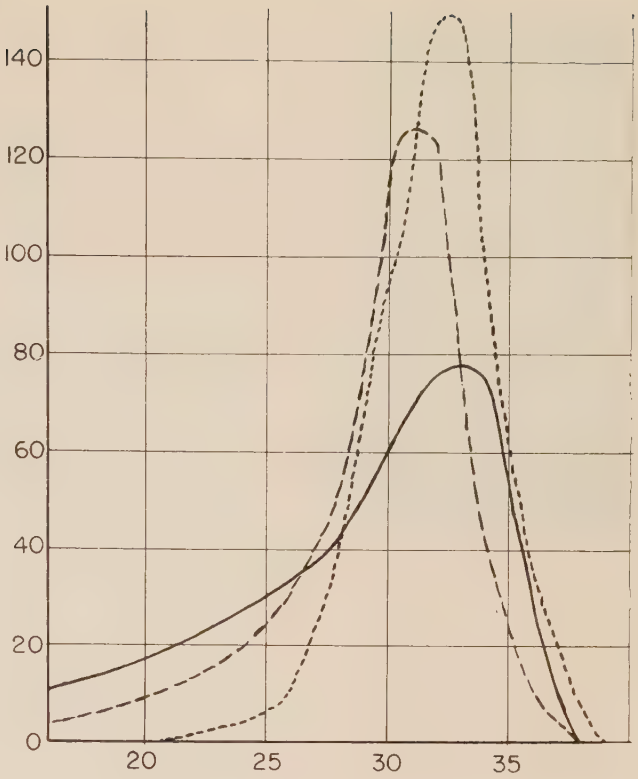

Fig. 9. Hardness distribution in three paper mills

preceding. As can be seen from Fig. 6 the corrections necessary are often considerable.

Because of the persistence of the irregularities in the average basis weight pattern, it was surmised that reel quality would be affected. This led Gavelin to develop a device to measure the hardness of paper reels and rolls. The instrument is patterned on the scleroscope and uses the height of rebound of a round ended steel cylinder dropped on the paper under controlled conditions.

Figure 7 shows the variation in hardness across an individual reel. A large amount of information was collected,

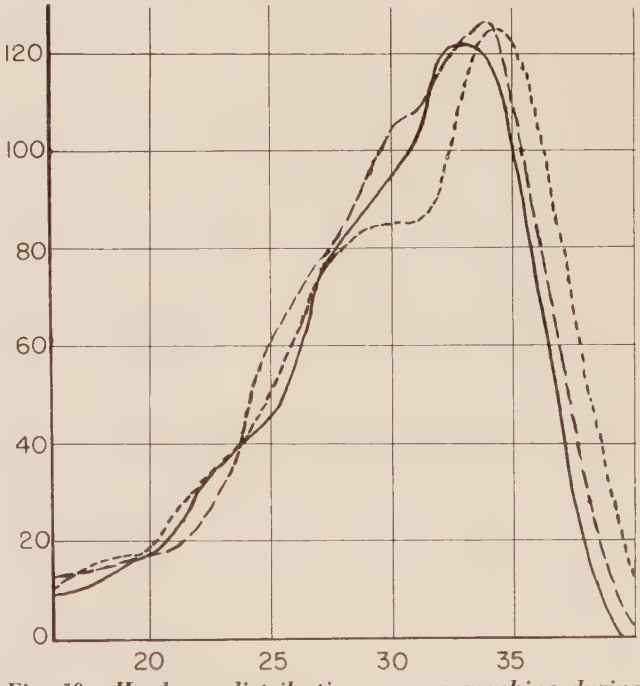

Fig. 10. Hardness distribution on one machine during the three shifts

Fig. 11. Hardness tester

but it turned out that the correlation between substance and reel hardness was not significant. However, the correlation for caliper was in the highly significant class which lends confidence to this sort of measurement. It is particularly useful for determining quantitatively a very important reel property.

Figure 8 compares frequency distribution of reel hardnesses between wide and narrow machines.

Figure 9 gives a comparison between different mills while Fig. 10 compares three back tenders.

Gavelin will publish his work on reel hardness shortly and since the topic is not too pertinent to Burkhard and Wrist's paper, I would suggest that if you are interested in more detail and cannot wait that you contact him by mail or see one of us after the meeting.

Figure 11 is a photograph of the hardness tester.

Moderator Stamm: Thank you all. The meeting stands adjourned.

FRIDAY, SEPT. 24, 1954

The final panel discussion and question period convened at 2:30 p.m., John C. Wollwage, moderator presiding.

Moderator Wollwage: The members of the panel not already introduced are—on my far right, Dick Calkins from Riegel Paper Co., in charge of research. He will lead the discussion on Dalton Shinn's paper on the measurement of draws and speed variations on the paper machine.

Rudy Griesheimer, directly here on my right, is from The Mead Corp.; he will lead the discussion on the Nash-Malmstrom paper.

On my left here, immediately to my left, is J. d'A. Clark, who is going to discuss Mr. Rance's paper.

And then just beyond him, Otto Brauns, of the Central Research Laboratories of Stockholm, who is going to discuss Mr. Ivarsson's paper.

Can we start off, Dick, with you leading us off with the paper of Mr. Shinn's?

Calkins: Mr. Shinn has described for us a very interesting and useful device which has met the specific needs of this particular problem.

The use of the oscilloscope to locate short term variation is an ingenious technique which we are going to find valuable.

However, there are several points, which, to the observer, warrant some elucidation and discussion. This is true both from the standpoint of the author and, I hope, from the experience of some of our symposium members.

First, what checks of accuracy of this device have been made and what precautions were taken for the satisfactory location of the measurement wheels themselves? I would like to know what you consider the inherent accuracy of the total method and not just the device itself.

Now, the second question is somewhat related. You have reported negative draws at the wet end that would appear to warrant further investigation. I find it difficult to devise an explanation of such a thing on the machine. I have observed it in my own limited experience.

Third, the comparative data that you presented on the steadiness of various types of drives need more elaboration. It would appear that you would compare the driers not only by type but by speed range and possibly by type of paper being made.

Finally, I was very glad to see Mr. Shinn include some preliminary data on the effect of draws on sheet properties.

I should like to make some additional comments.

First of all, I might add that I realize the preliminary nature of this work. The directions reported are, I believe, fairly high compared to the conventional machine. This may be due to formation or due to drier draws or shrinkage in the drier. I would like to have Mr. Shinn comment on that.

From our own experience we are manufacturing a very wet porous sheet of paper, which, in order to make at all and to meet specifications, we practically eliminate the draws. We have done this by running a long felt the entire length of the wet section and have only two wet draws, running them on an absolute minimum. We are running from 1.2 to 1.5% draw over the entire machine.

With this brief and in no sense comprehensive introduction, I hope that Mr. Shinn will clarify some of these things for us in order that we may have a further better understanding of the subject.

Shinn: Now, as to your first question—you wondered about the checks and so forth on the accuracy of the instrument. That is a little bit hard to do overall in that we have nothing to check it against. None of the machines that we tested have any built-in instruments for indicating draw or, or, at least if they did, they were not operative at the time.

However, we can make spot checks of the accuracy, for example, simply by reversal of the two wheel units. For example, we measure two points and get a draw of, let's say, 5%, and then we can reverse the location of the two wheels so that any difference in the diameter of the wheels, or any difference in friction which might cause slippage would immediately show up in the result. In these experiments where we have reversed the two wheels we have never found anything significant at all.

Now, there are, in measurements of this type, certain errors which can only be eliminated, you might say, by the averaging of several determinations. For instance, when you start the period of counting, and I am referring now to the revolution counter, you don't know whether the switch has just opened or just closed at the wheel. In other words, there is a period of indeterminism at the beginning of the counting cycle amounting, possibly, to one count. In other words, if the switch has just opened when the counting period starts, then you miss that first revolution.

There are two cures for that trouble. One is to make your counting period quite long so that the error at the beginning and at the end is of small percentage.

Now, that is not too practical. For one thing, it takes too long to make the test and the men holding the wheels tend to get tired, and so we have settled on 30 sec. as a reasonable length of time. On a machine running 1500 f.p.m. in 30 sec. we get 380 or so counts, so that we have an error of one count at the beginning or possibly one at the end, then we have a possible error there of about two in 400 or roughly a half of one per cent possible error.

On the other hand, that is bound to be materially reduced by running several check determinations and taking the average.

We have never based any results on single determinations but rather on two, three, or four. Therefore we feel that the error is not very great.

As I believe I have mentioned in the paper, there is some possibility in some cases of a little slippage between the measuring wheel and the surface being measured. We always avoid measuring any smooth surface if we can. A roll surface beyond the travel of wire or felt is avoided because it may have an accumulation of slime and if it is wet then it has become skiddy.

We always measure our wire directly, which obviates any error of slippage of wire on the couch and we prefer to measure on the drier, or on the drum or reel.

Now, we come down to the second question, this matter of

negative draws. We do not know the answer to this. Whenever we come to a problem such as this, we are very careful to make an unusually large number of checks. We check over and over and reverse the wheels and we do everything that we can. However, on a machine that shows negative draws we consistently get that value.

We are wondering if possibly there is such a thing that in the use of a vacuum couch, you have removed sufficient water from the sheet that the sheet has a tendency to shrink slightly at that point. If so, it may be that you can apply enough tension to remove the sheet from the wire and still end up with a net loss on the sheet dimension. That is a possible explanation.

I don't know of any error in our instrument which would account for that. Therefore, aside from this matter of possible shrinkage due to high water removal at the vacuum couch, I am at a loss to explain it. However, we have seen it and checked it frequently enough that we feel in our own mind the effect is actually present.

However, I would like to call your attention to the fact that any case which we have run into has been very small, compared to the positive draws. In relation to that the negative draws are indeed very small.

I am afraid that I did not get the detail on the last question.

CALKINS: That concerned the comparative data on the different types of drives. I suggest that it might be worth while to compare them.

SHINN: As I mentioned in the paper, I believe that the order of listing them would be the same if they were compared as to percentage variation as they have in actual variation. However, I don't have available at this time the tabulations according to speeds and grades of paper. However, we could get that. It would be a little bit difficult to do from the preprint because all of our machines are simply indicated by letter. I am sorry that I do not have that information.

MODERATOR WOLLWAGE: Are there any questions from the floor that might be answered at this time?

CALKINS: We have one from Mr. Stephenson, who has listed the different shrinkages, the different draws here on the board, and he makes the comment—"can these be related to shrinkage on the drier and has it any significance as to paper quality?"

SHINN: I may have been a little confusing in my listing of the draws. Actually, in setting up that experiment in A, that was a draw of 4.6% between the wire and the first press only. In experiment B we had a draw of 3% between the two presses with number A draw reduced to essentially zero. In other words, in the first three series of draw studies, A, B, and C, those are draws in those positions only. The other draws were reduced to zero. In the final experiment the three draws add up to 5.2%. All of these tests were made on paper which we dried in the normal fashion so that as far as the drying conditions are concerned, they are identical insofar as we have been able to control it.

The question has been mentioned, too, about the fact that the ratio of machine to cross direct tension is quite high.

Normally, in a paper machine it runs somewhere around 2 to 1. Here we are a little closer to 3 to 1.

One reason is that at slow machine speeds, we had quite a rolling action on the wire. The slice velocity was considerably higher than the wire velocity, which tended to give us a machine direction orientation. The shake, of course, is not sufficient to neutralize the action of the rolling of the stock on the wire.

Now, this study simply ignores the effect of shrinkage in the driers. That is a separate problem in itself.

The driers are all of uniform size, and there is one top drier felt and one bottom drier felt; and I will say this: that on the small machine, our so-called edge effect probably extends clear across, with a 2-ft. trim. We probably get fairly free shrinkage clear across the sheet, as you would get on a larger machine, only in the edge foot or so.

So, as far as cross-machine action is concerned, we correspond, no doubt, to the edge effect on a large machine.

I believe that is all I have on that.

JUSTICE: We have noticed this negative draw, too, and particularly on the later machines where we are running with your type of mechanical setup and the draws are held very low.

I reported some of these negative draws in Roadman Reports and got laughed at so I checked again and found them to exist. I think I have a partial explanation of why they happen if I can use a blackboard a minute.

They happen on press, particularly on first press, and sometimes on second press. But on a press (drawing on blackboard), we will draw a top roll; now, if we put the rubber cover on that top roll, it will be thinner here (in the middle), than it is here (at the speaker's right).

Now then, we take a radius, R-1, and another radius, R-2, that says that this surface is going to travel faster than this (indicating) going through the nip; but that is not all of it. Actually, this rubber cover on the outside is a volumetrically incompressible thing. It is deformable, but you don't change the volume very much.

So, if you are traveling a certain speed through the nip, and the same number of pounds pass this point at this point (indicating), and you have a smaller cross-sectional area here than you have over here (indicating), this point is traveling past faster. And the softer the rubber cover the greater this effect will be. You can measure it very well, even with the better type of hand tack.

Then, the other thing I would like to ask, a question on most of these press draws, where you are measuring on the plain top roll: I have tried a lot of different presses, too, in setting up say a new machine, to try to set the draws initially so you go through. The problem has always been, where do I put my draw indicator? Where to set it? You can read on the felt roll going off—on the top roll—or, on this bottom roll, if you can get inside the felt, inside the saveall here; and you can get figures different in those three places; as much as 3 or 4% on a given press.

So, on the machines where we—on mechanical drive machines—calculate and use a relatively hard cover on that bottom roll, and we think that the surface of this roll here is more nearly indicative of what is going on as far as draw speed right on the suction roll.

On a machine that started up not too long ago, we were trying to set draws through the machine—before start-up—and we couldn't get the first press measuring up here running faster than the couch, but it ran well.

So, now then, I would like to ask, on that paragraph, Fig. 5, you were talking about machine speeds—is that machine speed or draw?

SHINN: That is variation of machine speed.

JUSTICE: So, then in your talk of electrical drives, or mechanical drive, actually what we are seeing there is the speed regulator of the prime mover; is that right?

SHINN: That's right.

JUSTICE: And were those taken on presses, couches, or actual drier sections?

SHINN: Actually, what we've done there is to analyze the whole machine for speed variations, and those represent the points at which we found the maximum variation. In other words, those represent maximum values on each of the machines tested.

JUSTICE: But they would be a function of the entire drive, including the governor, speed regulator—including prime mover on mechanical drive?

SHINN: Yes.

There is one point I might mention, which I forgot to mention in the talk, and that is that you have an effect coming in on some machines that may be quite serious. That is,

certain sections of the machine have a very much higher inertia than the other sections—for example, the driers. We have actually measured cases where, in the rather sudden machine speed change on a line shaft machine, the driers were slow in taking up the change. In other words, the presses, wire, and reel would all speed up immediately, and the driers would actually come up to the new speed; and that, of course, can throw peculiar actions into the draws, at both ends of the driers, and may cause a break either way, either at wet end or dry end.

So, that is a very important consideration, although we didn't find it generally. I think there were only two machines in which we observed it—I think it might be a serious consideration in some cases.

JUSTICE: On that problem, just with the machines on line-shaft drive—that is the only case you observed?

SHINN: That is the only case we observed.

JUSTICE: And in those cases the rate of change on the governor on the prime mover in such a machine should be set usually about 5 min. for a total machine, 5 to 7 min. You can eliminate this problem. Otherwise, speed changes on machines with line-shaft drives a lot of times will cause breaks.

SHINN: Are we talking about the same thing? I'm talking about a change that happens during a run, not during a speed change made by the machine tender; but a machine speed variation during the running.

JUSTICE: That is prime mover regulator, then?

SHINN: Yes.

MODERATOR WOLLWAGE: Are there any other questions?

STEPHENSON: I'd like to ask whether the introduction of the vacuum pickup is going to throw out any of the conceptions that have been introduced here in connection with this study?

SHINN: In the list of machines on newsprint you will find that there is one machine with vacuum pickup, and we found on that a zero draw at the pickup.

However, between presses there is a transfer from one press felt to a second press felt, simply a gap; and there is a very considerable draw at that point—quite a bit larger than normally would be found at that point in a conventional machine. We would like to see that reduced, because we have gone to the trouble of getting a vacuum pickup, and apparently we are not taking full advantage of it in the whole wet end.

Possibly, we are wrong, but at least we're disappointed that they haven't reduced the draw at that point. However, at the pickup it appears to be zero.

JUSTICE: That machine with the pickup—that is the no. 2 machine, the way I understand it. That has a very stringent run, I would say, for the sheet and the felt between it—what is the second press and the third press?

And also on that particular machine there is an extremely long draw of about 30 ft., I believe, between the second press and the drier section. We have noticed that on a machine having those large press draws, but we believe it is a function of the particular design on that machine. The data on other pickup machines will show that you still retain your low draw between the couch and the second press, and then you can have regular, normal draws onto the drier surface.

That machine has really some special characteristics to it.

SHINN: In other words, theoretically it isn't necessary to run . . . .

JUSTICE: In these data on the suction pickup machine, the draw condition between the second press and the third press, and between the third press and the drier, is aggravated by special felt runs—and being an old machine, particularly a long draw where two other presses are taken out and just space is left there.

STEENBERG: Mr. Gallay yesterday showed the case of strain hardening, and it applied, also, to the very wet sheets.

Obviously, if you have to have a draw, you must get quite a lot of elongation on a sheet that never before has been stressed, because it has to strain harden. So that is the reason why this, in the first instance, rather unexpected large draw occurs once when you get it. So, when you have a draw—well, there your elongation comes, because in the open draws the material is already strain-hardened by the preceding draws. That is the explanation of it, I think.

SHINN: There is one point, if I may enlarge on that just a little: from these data here on the board, I might have mentioned that these draws are the maximum possible without brake. You will notice the draw between the wire and the press is considerably larger than the draw between the first and second press. In other words, we remove water on the first press, and therefore, although it hasn't been stressed prior, it still cannot be stressed as much, because it is at a lower moisture content.

So that apparently, as we reduce moisture here, whether the sheet has been prestressed or not, we found we could stress it a lesser amount.

F. T. RATLIFF (Personal Products Corp.): Mr. Shinn, in looking at your Table III, I notice that you are measuring positive draws in a good many places on Yankee machines with pickup felts. Is it possible there should be some slippage somewhere in those felts?

SHINN: Well, I do not know—it never seemed to me that it was necessary to have the same, zero draw, when you had say a felt running, the same felt running through the two presses, due to the elasticity of the felt. I rather imagine that you may not have any slippage of felt at the pickup, but you probably have elongation of the felt between that point and the press, so that the sheet and felt together are being elongated.

A. P. YUNDT (Camp Manufacturing Co.): I would like to utter a little word of caution. This business of using the time base of the oscilloscope as a reference point, and then observing the frequency changes as the pattern drifts right or left—you have to be very sure that your time base is steady. Particularly with some of the older model oscilloscopes, which used a gaseous type tube, it has been found that they are very susceptible to difficulty in connection with the voltage regulators. A constant voltage regulator transformer is sometimes not a very constant source, when used in connection with the regular mill supply with variable frequency. The modern, hard vacuum tubes used in the time base, as opposed to some of the older gaseous type discharge tubes, will not expose you to such frequencies.

One way of checking is to use variable voltage on your oscilloscope, and see what that does to a trace of your power line frequency.

SHINN: I think I can answer that. The oscilloscope we used does not have a gas discharge; but it has a multivibrator, using regular resistance capacitance circuit, and as a precaution we shorted out, or grounded the synchronized circuit in the scope so there is no chance of synchronization coming in.

We also operated the scope at varying voltages to determine the effect; and we find that at the use frequency, that is, the horizontal sweep frequencies we were running, that a drop in voltage of 10 v., say from 115 down to 105, gave us a horizontal drift of 3 cycles, 3 wavelengths per second only.

YUNDT: I recognized the oscilloscope that you used, so I knew what you were doing; but it was mostly a word of caution, because older oscilloscopes do exist. The particular design you had was not common in the field of 'scopes until about 2 or 3 years ago.

SHINN: That is an 884 tube, I think you are referring to.

YUNDT: Yes; or an 885.

DURWOOD GEFFKEN (Oswego Falls Corp.): What is the caliper of that sheet there?

SHINN: I don't have that information. I'm sorry.

GEFFKEN: Have you any rough idea?

SHINN: It was a 50-lb. sheet. But I don't remember whether we had any loading on our calender stack at the time. I would imagine we would have a bulk index of 115 or 120. Bulk index is simply caliper divided by basis weight.

I'm sorry I don't have that figure available.

GRIESHEIMER: I would like to ask one question, and I think it is a rather obvious one, with respect to the actual stability of this system. Has there been any experiment under which these two wheels are operated on the same drier, for example, or on the same cylinder? And in which case what is the long-term stability?

SHINN: You are talking about the stability of the oscilloscope?

GRIESHEIMER: Yes.

SHINN: That isn't necessary. All you have to do is put the 60-sec. cycle voltage on the vertical plates, and set your picture so it stays constant and see how long it stays. There you have exactly a 60-sec. cycle input.

We find that is quite stable. You can set it in a given position, and it will stand there maybe 30 sec. to a minute; and then possibly a little drift develops, very slowly. But it is nothing in the same category with those observed on paper machines. In other words, if you can get a pattern that will stay constant for 30 sec., for our intents and purposes you have a constant frequency.

GRIESHEIMER: Another question in a somewhat different vein—has there been any effort made to combine the outputs of these two generators in order to produce frequency, and thereby eliminate entirely this horizontal time sweep and possibly thereby have a means of getting a very extensive indication of a change of one speed in respect to another?

SHINN: We have done that, however, we didn't approach it from that angle. What we did was to keep our horizontal oscillator operating on a regular sweep; then we put gears with an equal number of teeth on the two wheels—I believe it was 50. Then we fed those two signals into an electronic switch, which, essentially, lets you look at the two signals at the same time on the scope face—one directly over the other. Then, if you have a very small value of draw, you have your two sign waves, one directly over the other; and if one moves the least amount with respect to the other, you see it. In that case you are not depending on the accuracy of the horizontal sweep; you are simply comparing one alternating current with the other.

We found that had great value in certain cases, but was limited to values of draw, for example, which were almost zero, since if one pattern started to drift very rapidly as compared with the other, you were unable to count the nodes as they passed.

We got some value from this technique, and with zero draw we could get a direct comparison without regard to our sweep frequency.

YOUNG: Another suggestion is that you can use your two gears of equal numbers of the teeth and then count the envelope of the two as they are beating against one another with your mechanical counter and then you can expand that draw to quite accurate determination of draw over a period of time, say 30 sec. or whatever you want to make it. However, that requires circuits that you cannot buy ready-made.

SHINN: When we started out, we did not realize the difficulty in measuring draws. Actually what you get into is this: the pattern on your scope is simply a high amplitude wave across, or perhaps a straight line across—ordinarily a high intensity wave and a straight line. The difficulty is that you cannot determine which way the drift is going. You get a variation but then you cannot tell whether that drift is to the right or left.

YOUNG: Just match your time base with one of the things that drift to the right and if it is lower then the drift is to the left.

CALKINS: Mr. Justice has explained only what is apparent in relation to measuring negative draws and on the felt the negative draws simply do not apply due to the things pointed out by Mr. Shinn. On the felt I would not argue about negative draws due to the felt stretching or shrinking.

JUSTICE: What I said there was that I didn't think that the negative draw existed. I just thought we measured something there that the top row would indicate existed or of something that you thought was there.

SHINN: I might say that the negative draws were measured on the felt after the felt had gone around the first press roll. I don't know.

Now, let's say that the felt is at minimum tension, directly after the press and the maximum tension just ahead. That may be a part of it.

I feel quite sure that we have checked the other points in those cases and checked ourselves that it is negative. However, the usual place to measure the press speed is at the felt or over the felt roll after the press.

JUSTICE: It would be a very interesting study, just on a given press, to go all the way around it, to go around it every place that you can find and see what happens.

Now, another interesting thing that I have always wondered about was the matter of the difference in the speed of the wire, before and after the couch. The wire must be a little longer on the top roll going into the couch than it is coming off. I have always wondered if that little bit of slippage going around the couch surface would not explain some of this.

SHINN: It is true that there is a lot more tension in the wire before the couch than after. I have seen figures based on couch motor power where they calculate that the tension required to pull the wire over the boxes is something like 3000 lb. so that it could certainly be possible that there could be an elongation between the box and the couch.

MODERATOR WOLLWAGE: There is a lot more that we could say about this. Nothing has been introduced about the use of measuring draws by considering the ratios. I will ask the group to discontinue this discussion and we will move on to Mr. Brauns for a discussion of Mr. Ivarrson's paper.

BRAUNS: Mr. Ivarsson's name belongs, as you all know, to that group of men who, in the last 8 or 10 years, have contributed so amazingly to our present knowledge of the behavior of paper under stress. He has been particularly interested in the changes taking place in the paper as it is being dried.

So far, much experimental evidence has been produced to elucidate the problems under consideration and also to start speculation. The philosophying thereafter inevitably leads to equations to fit empirically the curves in various plots, or to theories of fibrillar action or surface tension of more than one kind to satisfy our craving for explanations.

Mr. Ivarsson's philosophy, as proved by his paper, has been of quite a different nature. In fact, he has turned his mind to thermodynamic laws, the validity of which rests well assured. He is truly blazing a new trail, and it appears to me that he has succeeded well in reconciling difficult theoretical reasoning with the fundamentals of papermaking, which is the true object of this remarkable symposium.

At this point I should like very much to divert for a moment from the subject. It comes to my mind that during our discussions, and in several papers, reference has been made to Mr. Barkas of the Manchester University. In fact, that man has contributed a great deal to this meeting without even being present. I understand that he was invited and that he would have liked very much to be with us if this had been possible.

Now let me return to Mr. Ivarsson's paper. Those of you who have spelled your way through it will have noticed the disposition. It begins with a brief review of the thermodynamics underlying the processes that Mr. Ivarsson is studying. Actually, we shall have to accept this part without much discussion since we would have to go back to the original literature to follow the deduction of the various equations.

I call your attention to the author's remark, however, that he applies the mathematics under the assumption that the cellulose is approximately elastic in the range of stress-strain under consideration.

Some of you may wish to argue on this point; personally I have no axe to grind. I don't even object when the author says: "The results should not be interpreted as valid in general for any sample . . ." even though this opens all avenues to escape critical double-checkers as J. d'A. Clark. I feel that the attempt made by the author to show us the way to really sit down and calculate what is going to happen to our paper is sufficiently commendable to take the sting out of any impertinent questions.

1. If we turn our attention to the experimental part there is one question which I consider fair to ask. How did you determine the moisture content of the strip in the tester? Did you bring the tension up to a certain point and then did you take the strip out for a moisture test? If so, you could, of course, not have used the same strip over again but you would have to use a new strip. I suppose you must have used some device like a beta-ray gage or similar arrangement. Perhaps you would enlighten us on this point.

2. My next question is prompted by the remark Mr. Ivarsson made yesterday on Mr. Gallay's paper. I noticed that on his diagrams he uses stress, and not force. I suppose this is quite necessary for the quantitative calculation to follow. It would be interesting to know just how Mr. Ivarsson measured the changes in area of the strip during his recording of stress and strain. I leave it to the audience to make any further comments on the experiments.

3. With regard to the results shown in Fig. 9 it shows stress in different papers at varying strain. One interesting fact is the moisture lines drawn through this diagram. If we have a paper against a drier we presumably deal with a moisture gradient from one side to the other, that is, perpendicular to the sheet. In the same paper different stress would occur for a certain total strain in the drier section. Now, would this imply that the sheet is subjected to a shearing stress as well and would this have anything to do with subsequent curl?

4. Further, if you knew the adsorption isotherm for the two pulps in a duplex board do you mean to say that you could calculate the stress conditions during their drying? The stress being different in the two plies would give rise to very interesting comments which we all would like to hear very much.

5. Finally, what would you rather do if your theories were to be followed in a practical way, determine adsorption-isotherms or take a diagram of the type you showed in Fig. 9? I believe I can anticipate your answer but if we have it delivered it may dissipate some misconception of your work.

Moderator Wollwage: Now, do you want to pick those up in order?

Ivarsson: I will try to.

1. First of all, I would like to indicate how the moisture content was determined. To begin with, we took out samples after a given stress was reached in the paper strip. We put it into a weighing bottle immediately and determined moisture by drying and weighing. This is not always very practical so we also tried to use a resistance measurement. This principle is applied in commercial instruments used for determination of moisture in paper and board. For a given material it is possible to calibrate the resistance against moisture content within the range of the study. This involves the determination of very high resistances, on the order of thousand megohms. It was possible to use this method down to a moisture content of about 4%. In the data that I have presented today, we have not gone beyond that point.

2. The next question concerned determination of the dimensions of the sample in a work like this. It is quite important that data for stress are given per unit area for later quantitative calculation and reference work. This has too often been neglected in published work in this field. The external dimensions of the paper strip being tested can be determined with relative ease by use of a microscope attached to the instrument and by a good caliper gage.

In this work, the determinations have been done after the final stress equilibrium was reached. It is questionable, however, if the cross-sectional area should be taken from external measurements or should be given as the true cross-sectional area of the fibers that pass through the cross section. In my paper the sample has been assumed to be homogeneous and calculations refer to dry samples only. From equation (7) it can be seen that Q, the dry weight of the samples, enters the expression for drying stress and consequently by knowing this quantity the corresponding stress can be calculated *without* knowing the external dimensions.

On the other hand, if we assume that the equation is correct and know the corresponding values for stress and change in moisture content we can determine the value for the directional swelling Ay. That is actually what we did first and it was found that the values came out close to the measured values for free shrinkage s_f. Even if we have to account for plastic flow present in the wet paper web under stress the given theory has been very valuable for understanding the problem in general.

3. When paper is dried on a drier it is very likely that there will be a difference in moisture content between the surface against the drier and the surface against the felt with a corresponding difference in stress distribution throughout the cross section of the sheet. If the paper web leaves the cylinder surface without a felt for support it will have to deform to reach a stress equilibrium, or in other words, it will curl.

4. Uneven stress distribution is more likely to occur in a board made from various plies with various furnishes. Let us assume that the uppermost curve in Fig. 9 ($s_f = 0.19$) represents the drying stress shrinkage curve for the liner stock and the other curve ($s_f = 0.115$) gives corresponding data for the stock used in the back of the board. In the machine these layers pass through the drier section together and are not supposed to separate. This means that the dimensional changes in the plane of the combined sheet will be the same resulting in a stress difference between the top and bottom layers.

If curves, as in Fig. 9, are known for the particular sheet being run, the stress difference is easily found by taking data from the curves at the same value of s. It is also demonstrated that an excessive draw is of no good if an even stress distribution is of importance.

5. Calculation of drying stress following the theory discussed requires moisture content–vapor pressure diagrams for the material tested. Data in Fig. 3 have been taken as averages from the literature and are regarded as accurate enough for the work presented. Actual determinations require precision apparatus, for example, the type used by Mr. Stamm at the Forest Products Laboratory in Madison. It is more likely that actual stress-shrinkage data according to Fig. 9 are of more immediate value for the practical papermaker.

Brauns: I have just one more question here from William H. Stine, Champion Paper & Fibre Co., Hamilton, Ohio:

"Please comment on the theoretical prediction of change in system volume upon hydrogen bond formations."

Ivarsson: In a paper given about a week ago in New York, Mr. Nissan, from Leeds University, took up that subject; and he showed that it is possible to calculate the stress-deformation curve, knowing the energy equations and displacement of the two surfaces, or the two molecules involved in the hydrogen bonds. That is quite an accomplished theory. Actually, there are many theories developed at present; but I think that I have to leave that question to somebody who knows more about that pure theoretical subject.

Steenberg: I think that this type of work Mr. Ivarsson is

carrying out is a rather important type of work because it is quantitative in its aspects; and it is based on a few assumptions, and rather simple assumptions. They will not give all the choice, but it is really something you can work on, because it is not just words. In this field there has been quite a lot of things written in the last years, which are just "belief." And a lot of these "beliefs" have been very belligerent beliefs, which doesn't make things much better. There is, of course, no trouble to explain a lot of things if you introduce a sufficient number of hypotheses, especially hypotheses of the type that are impossible to test, which is the classical religious method of introducing hypotheses.

As a matter of fact, I think that we should encourage further work of this type.

THELLER: When you dried your strips of the paper in the jaws of the stress-strain tester, the two ends of the strip which were covered by the jaws of the tester must not have dried out as rapidly as that portion of the strip exposed to the air of the humidity room; and there must have been a moisture gradient right at the clamp.

Do you believe that this gave you much difficulty as far as accumulating breech at that point and a large relaxation of stress at the clamp?

IVARSSON: This was actually quite a problem to start with, but after some time you find that the length of the sample actually isn't too critical for the drying stress you measure. I have been using a clamp in which the paper strip is (drawing on blackboard) wrapped around a rod, and falling over here (indicating); and on this side is a clamp (indicating). You see what I mean. I have a pressure between this rod and this clamp here (indicating), so, when I was using the infrared heat the radiation here would dry it up to this surface. Actually, and as far as the experimental data show this does not introduce an error in the results. I have been thinking of it quite a lot.

LYNE: I might confirm that observation of Mr. Ivarsson's.

We have had the same problem with our wet web, and one of the reasons for going around the right angle for our clamping was to obviate that difficulty on the corners.

We have checked it microscopically and photographically, and find that there is very little transfer of forces around it, beyond that tangent point.

MODERATOR WOLLWAGE: Are there any other questions? If not, we will proceed to Mr. Rance's paper; and Mr. Clark will start us off on that subject.

CLARK: Gentlemen, it is an inevitable drawback to meetings of this kind that there is rarely adequate time for an orderly presentation of differing viewpoints.

For example, certain aspects of Lyne and Gallay's positions, as in the presentation yesterday, or Mr. MacLaurins' paper, or, as I shall do now about aspects of Mr. Rance's paper, obviously do not mean that these authorities are wrong; but just that, as many of them, after listening to a paper by me, perhaps would legitimately attack my presentation on the grounds that my position on many aspects of fiber properties, like freeness and fibrillation, was too extreme, and, except for my position on the freeness test, it may well be.

Now, Mr. Rance doesn't know it, but I took him with me on a boat trip to Alaska this Summer; and since we just had about $2^1/_2$ hr. of sunshine in 12 days going up there and coming back again, I had time to read and in parts re-read that excellent book of which he is co-author with Mr. Barkas, on the mechanical properties of wood and paper; and I heartily commend it to you.

To me it is unfortunate that in recent years there's been an apparent swing away from a recognition of the importance of fibrillation in the beating phenomenon. And I think undue emphasis has been placed on the swelling of beaten fibers, and on things like freeness.

One can believe that the sun makes a daily rotation around the earth and thereby estimate the time of day and make other uses of the theory, but it's a poor, even a hopeless concept, to adhere to if one wishes to investigate the true nature of the solar system.

So with freeness and the plastic adhesion theories. They successfully predict a great majority of phenomena, and even freeness may be useful, I will allow, as control test in a groundwood mill—maybe, but I don't think it has any place in a scientific discussion or gathering such as we have here today. It is too empirical. However, many aspects of the plastic bonding theory of beaten fibers are valid, and, indeed, necessary to explain certain findings.

Maybe without boasting, very likely I personally have made as many freeness tests as anyone in this room. I did nothing else for about six months, once upon a time. Today I never use it to explain stock phenomena, since—and this is an important point—the freeness test is looked to for an explanation only when there is an anomaly to explain, and that is always when new conditions are present, or on new materials like glass fibers—when any conclusions are highly questionable.

Mr. Gallay talked yesterday about the freeness of glass fibers—you know that really is awful, because there we are in a completely new freeness realm, and it should never be even whispered.

Now, it is the very time, when we are facing new set of conditions, that these superficially attractive, "self-evident" conceptions, like the sun rotating around the earth or freeness tests are most likely to put us in the wrong.

That is why I am so opposed to freeness. It may be useful in a mill, but there isn't one of you gentlemen who can explain what it means in scientific terms; and if you can't explain it in those terms, it is very unsatisfactory.

Now, any theory purporting to explain phenomenon that has an anomaly—and Mr. Rance has admitted his theory has at least two—is, itself, an anomaly, and I think it will be obvious to Mr. Rance that his theory therefore is only a tentative step toward a better comprehension of the matter.

Maybe if he and Mr. Cottrall in England, and Mr. Gallay and Mr. Lyne and their co-workers in Canada, and Mr. Brecht and Mr. Jayme in Germany, and maybe some of our colleagues over here, would just forget their old, perhaps unconscious, feud with James Strachan, and just think more about the nature of fibrillation, it would be well.

You know, if you look in an electron microscope or under an ordinary microscope at silvered fibers, you can actually see the fibrillae on the new surfaces, once the primary wall is removed. Since you can see them there, you should take cognizance of them.

They play a very important part in the relationship between cellulose and water. It isn't a trivial matter at all. It is a vital matter, I think, and, because of the profound effect of these fibrillae on the properties of both wet and dry sheets, they should help us to formulate more reliable theories to explain the different pulp and paper phenomena and perhaps without any anomaly.

A theory with an anomaly is really an abomination; it is subversive and should immediately be reported to the investigating committee presided over by the local Senator.

Concerning the importance or even the necessity of the role played by fibrillae—and mind you, my work that I have done this last 2 or 3 years on the manufacture of paper from dry fibers deposited by air, which are therefore smooth, with no fibrillae available—makes me acutely conscious of the importance of fibrillae.

If I didn't need them for bonding, we would really revolutionize the whole paper industry. But because we can't get them, and we can't use them, although we get plasticity and swelling, because the fibers are or can be wetted, we get no bonding except by adding an adhesive. We must have fibrillation in the presence of water for bonding. They are essential for both wet and dry strength, and I caution you gentlemen to think about that a little bit.

Now, if we accept the presence and the role of fibrillae, large and small, then the distinction between inter- and intra-fiber swelling really becomes quite clear-cut, and I think this concept would be helpful to resolve those anomalies.

It would appear to me, perhaps Mr. Rance, you may agree with me, that if you had a freshly made sheet of paper, and described its performance on drying, it would behave very much like a pristine fiber of undried pulp, direct from the digester. The dimensional antics of such a fiber—that is, a new fiber—when dried and re-moistened, and the hysteresis entailed, are much like a freshly made sheet of paper but on a micro scale.

Now, Mr. Rance's explanation for the anomalies he brought out are interesting and no doubt in part valid. I think they are excellent—such as the twisting and untwisting of the fibers during drying and wetting. But maybe the part played by the fibrillae is needed, as a supplementary explanation for both this and his second anomaly relating to the numerical values of the fiber and sheet contractions.

I feel that this presentation to us by Mr. Rance has been a most valuable and helpful contribution, and I know that I, myself, have and am going to derive a great deal of useful information and new thoughts from it.

RANCE: Could I say something in reply to that?

MODERATOR WOLLWAGE: If you would like to do that.

RANCE: Well, there is a bit of a question there.

First of all, thank you very much for the unsolicited comment about your reading companion on the way to Alaska. I did not know I had been up there; some day I hope I will be up there.

Fibrillae! You know, I don't think there is so much difference between us, after all, on this question.

I don't believe that fibrillae can bridge the gap between inter- and intra-fiber shrinkage, with free beaten pulp. But as I have explained in my attempted explanation of one of the anomalies, I do think that the presence of fibrillae may bridge that gap in the case of wet beaten stock.

I think the region where the expansion is of paper is very high and the shrinkage of the stock is very high—that may be an overlap region, where these two phases, as it were, coincide. I don't think, though, they coincide in the case of free and moderately beaten stock.

I think that is a specific answer to your question.

CLARK: That may be right but I wish that you would do just one thing to make me happy—I wish that you would get an unbeaten fiber and silver it and look at it under the microscope and observe it and its fibrillae and I think that we will then come still a little closer.

I have a couple of interesting questions here and the first one reads, "In the making of sulphite 60-lb. sheet, the front and back edges of the paper sometimes become grainy for about 6 in. from the edge, which makes the paper unsalable. If the sheet is thick in the middle, the grainy edge then also appears on each side of the water spit sheet. What is the explanation?"

RANCE: My opinion is that it must be the phase of surface tension contraction that causes that grainy edge. If you refer to a diagram in the printed paper, which I did not include in my talk, you will see that the variation of the expansion of the paper from the inside of the web to the edge is appreciable but not enormous. We would have something like three and a half at mid-web and five at the edge. The increase from three and a half to five would not be enough to cause the sudden emergence of the grainy edge. Therefore, I don't think that it is caused by the second phase of the shrinkage but by the first phase—the phase caused by the surface tension.

There is another point that I would like to make. The grainy edge is not only the result of shrinkage of the web inward but there is also the negative factor, that when lateral shrinkage is prevented then the shrinkage forces pull down the sheet in its thickness. Therefore, when you have freedom to shrink laterally, you haven't got that pulling down in the thickness. You don't get that smoothing out effect which you get when surface tension is concentrated in pulling down thickness.

CLARK: Now, I have just one question here before there may be some questions from the floor.

It is a question from William Stine, The Champion Paper & Fibre Co., and it says, "Please comment on the effect or influence of wetting properties or fiber surface on inter-fiber contractions, especially during the critical period of the water envelope breakdown and the introduction of air."

RANCE: Well, as has been said, I presume that the question must refer to the possibility of changing the surface tension.

You can alter surface tension by bringing in wetting agents and there is no doubt that you thereby considerably reduce the surface tension shrinkage of the paper. You can make much bulkier paper by putting wetting agents into the stock.

That effect, of course, starts off in the surface tension phase. However, it has a secondary effect in the latter phase because if the fibers are not pulled together by surface tension, they cannot then stick to one another and cause the second phase of web contraction when the fibers themselves shrink.

Now, I do not know whether that is a sufficient enough answer for the question wasn't too clear. If that is not the answer then perhaps the questioner would enlarge upon it.

STINE: I didn't mean that. It doesn't answer exactly what I meant. Perhaps I could generalize and say the condition of the fiber surface—could that introduce or be a significant point somewhere along the line in the sheet shrinkage?

RANCE: By the wetting condition—do you mean the contact angle?

STINE: Yes.

RANCE: That would alter the situation because that in effect would alter the surface tension force.

MODERATOR WOLLWAGE: Does that complete the questions?

CLARK: Yes.

MODERATOR WOLLWAGE: Are there any questions from the floor?

STAMM: I would like to use the board.

First of all I would like to say that I enjoyed the papers of Rance and Ivarsson because they are both involved in things that I am very much interested in myself.

Unfortunately all the measurements that I have made regarding swelling and shrinking have been on wood, but fortunately recently I have accumulated a little data on paper and I would like to point out a couple of interesting things which I think will help to clarify the discussion back and forth here on intra- and inter-fiber swelling.

In the case of a piece of wood, all of the fibers are cemented together permanently. The lignin holds them together. Except if you destroy the piece of wood, that lignin bond remains intact and so all of the swelling is intra-fiber swelling.

When I started studying paper, I immediately found that there was more swelling than you could get from the fiber itself.

That I have been calling dispersion but then you could call it inter-fiber swelling.

I would like to draw just a brief diagram to illustrate some of that.

I have been plotting volumetric swelling and the reason that I use volumetric is that I feel that in all swelling studies, even though we are interested in paper only in the sheet direction, we are not going to get the fundamentals of it if we neglect the swelling and, most important of all, the thickness direction. Therefore, you have to take that into account even though you may not care whether it occurs or not.

Now, I am going to plot that against the density of the paper.

I started out making a few measurements between oven

dry and water-soaked and the interesting thing is that you can get points anyplace on here (indicating). There is no correlation of any kind at all, but then that is if you take machine-made papers.

I had a few laboratory-made papers that were made as hand sheets and made under conditions where there were very little stresses and lo and behold, these things do line up a little better. The spread isn't nearly as bad.

Now, if I take these machine-made papers and I soak them in water and then redry them under careful conditions so that stresses are not put in them again and then reswell them, then they all follow along a system like this (indicating) and I can then draw a line through the origin.

I am not claiming that they all have exactly the same volume density relationship but then roughly speaking they all follow along the same line, at least pretty nearly.

I have calculated my swelling on the basis of a volume swelling so that on a volume basis it is easy enough to figure out theoretically what the intra-swelling would be.

In order to simplify the thing, I will omit any slight correction of water that might have gone into the fiber.

We might say roughly that water adds its volume to the fiber when it goes into the fiber. All right, in that case I can calculate a theoretical intra swelling line. The interesting thing is that I get one that is just about half of that one (indicating); meaning that in most of these papers half is the intra and half inter.

Now, the assumption that I have made there is this—that the spaces between the fibers act the same as the lumen in wood. When you swell and shrink a piece of wood, the fiber cavity remains virtually the same size.

All right, I have assumed that that same thing is true in paper, that the fibers themselves swell but that the distances between fibers adjust so that the fiber space remains the same.

On that basis both of these (indicating) should be straight lines and, as I said, this one (indicating) is twice the other one.

One of the interesting things is that if you make regular wet-strength papers using a resin which tends to bond your fibers together, it is an advanced resin and isn't penetrating the fibers at all—then it does nothing to the intra-fiber swelling but it ties the structure together and cuts down dispersion and thus, under such conditions, I have gotten points that are just slightly above this theoretical line.

With a dimensional stabilizing agent that goes into the fiber, we will cut down on the inter-fiber swelling, as we have done in our work with wood. At that rate you can then get them below this line (indicating).

I feel that it is proper to consider inter and intra-swelling but I won't say fiber because when I say intra I am talking about either a fiber, or any unit larger than the cellulose chain. Now, as soon as it is a multiple of chains and water is going into the multiple chains, then it is intra.

Therefore, I don't think that you have to worry whether fibrillae are present or not to consider it in that light.

MODERATOR WOLLWAGE: It is all right if there are some fibrillae in there though?

STAMM: I don't care whether they are there or not for it doesn't make any difference in the results. Of course, if it is expressed in terms of strength then it is going to make a difference.

GALLAY: Now, it must be obvious that there is a contradiction of somewhat major character between the interpretation that we have been given with regard to our extensive data and to speculations given to us by Mr. Rance insofar as that region is concerned, which is up to about 75% solids—that is, where the fibers themselves begin to shrink. It is apparent, of course, that we could go into a great deal of detailed argument with regard to our differences.

Mr. Rance states, for example, that there is no inter-fiber bonding below a solid content of about 75%. In order to pursue that argument, I would have to rehash everything that I said yesterday, which surely would serve no purpose at this time. In the meantime, Mr. Rance and I have had a little private meeting and decided to continue this argument in my laboratory which he is going to visit 10 days hence.

I would like however to make this one point. Mr. Lyne and I have had a great deal of experimental data which, of course, require explanation. We have done a great deal of thinking on several alternative explanations and as a result we could find only one interpretation which seemed to fit all the results that we gave to you yesterday.

Therefore, it seems to us that unless and until someone provides us with an alternative theory which fits our data or, on the other hand, obtains further data which are at variance with our own, we feel that we must continue to consider our views as being reasonably tenable for the time being.

We have all heard Mr. Nissan several times during this meeting, and Mr. Steenberg a few minutes ago, talk about the value of speculation. I know that Mr. Rance would be the first to admit that general speculation cannot stand aloof from relevant experimental data—rather that speculation must include available data or deny their validity. I feel there would be no useful purpose served at present in considering further these somewhat opposed views. I did wish to emphasize the obvious on this matter of speculation.

RANCE: I don't think that I will add much about Mr. Gallay's contribution because we are going to discuss it a lot more in Ottawa.

It is quite obvious that there are two discontinuities. There is one which he found at about 40% solids and another at 75% solids.

Obviously we have to explain all of these discontinuities and the important thing is to find a theory that will reconcile them.

JUSTICE: I am kind of like the old colored fellow down home They gave him a watch but he didn't known how to tell time. One day he was asked the time and he reached into his pocket, pulled out the watch and said, "There it is, damned if it isn't."

What do these talks on fiber shrinkage with moisture change mean in the design of our drier sections?

I would like to have somebody talk or to say a few words about that. All of this laboratory talk has been fine but then do we change the design and all of that?

MODERATOR WOLLWAGE: I am going to leave that question on the record because if we are going to make anything like a 4:30 dismissal time then we are not going to start on that one. Unless there is somebody who feels that he has to say anything at the moment in answer to that question I would like to go on.

GALLAY: Isn't it obvious that he should be patient and wait for more of the lab work to be done before we answer that question?

MODERATOR WOLLWAGE: Well now, we want to spend some time on the Nash-Malmstrom paper, and I would like to have Rudy Griesheimer jump right into the discussion on it.

GRIESHEIMER: I am very pleased to have this opportunity to discuss the paper presented this afternoon by Malmstrom and Nash.

From my viewpoint I consider it a very worth-while contribution, and one needed for many years by those who are interested in supercalenders. At the same time, it is a paper that has several interesting and rather unusual aspects. It is on these that I would like to dwell for just a moment, before we get to the question and answer part of this discussion.

First of all, we realize that suddenly we have strayed far and wide from the paper machine, and have wound up in the finishing room. I think that this is rather unusual, because when we consider the banner under which this conference is flying—a banner of the fundamentals of papermaking—you will agree, I believe, that a paper on supercalendering is unusual, to say the least.

Now, it has not always been admitted by those in the industry that supercalendering is a part of papermaking. To illustrate the point, many of you, no doubt, have experienced the same thing that I have on one or two occasions, when a foreman from the machine room would approach the foreman of a finishing room in the following vein of conversation:

"Look here, Joe—*we* make the paper, and *you* put the finish on it! *We* make the paper, and *we* make it *right!* You're to put the gloss on it, and sometimes, all too often, you put the ridges, the curl, the cockles, and the buckles in it, too! You stick to your knitting, and we'll stick to ours. We'll make the paper, and we'll make it right. *You* content yourself with putting the finish on it!"

And so, I believe that the very fact that an august group like this is willing to audit a paper on supercalendering is really an encouragement for the fellow who has to operate a supercalender. Perhaps he, too, is a papermaker.

Secondly, it seems to me that the Malmstrom-Nash paper represents a rather unusual combination of a quite solid theoretical approach to a problem, with at the same time some interesting experimental aspects. In contrast to some of the other papers that we have audited in the course of these four days, it appears to me that this is not a development that requires a lot of future bridges to be built in order that you shall have something tangible. It is quite complete, and stands on its own two feet.

It has been said in the course of this conference (implicitly if not explicitly) that, by way of comparison, the Europeans approach their papermaking problems from a very fundamental or basic point of view, whereas we Americans are more inclined to look at such problems from a hard-headed, practical viewpoint. If there is any element of truth in that contention, then it remains for us to determine whether Nash is the European and Malmstrom the American, or vice versa. Certainly, both approaches have been considered by these two.

Thirdly, I would like to comment that their paper, unlike a majority of those that you have audited during this conference offers an opportunity for immediate and very practical application.

I have heard it said by several of the members of this conference, and I think unfairly, that the papers presented during these four days have been too "long-haired," that there have been too few concrete conclusions or too few practical things to "take home." In other words, it might be a little difficult to explain to the boss what has been going on during this conference.

Indeed, if that is the case, I consider it unfortunate that men in the industry should attend this symposium on the *fundamentals* or basic science of papermaking, and expect to take home therefrom bags full of practical ideas. Rather, I think that it is the obligation of the Fourdrinier and Cylinder Board Committees of TAPPI to pick up the torch and carry on from here, conducting subsequent symposia in which the more practical aspects of these fundamentals will be considered. Those will be the meetings that are more likely to satisfy the boss, but remember that they could not be possible if there were not these fundamental considerations on which to predicate the practical advances of the future.

In this paper, however, you'll find something really tangible to take back home with you.

If we forget for the moment the "high powered" mathematics that you saw in Mr. Malmstrom's slides, there are essentially two packages of information that have been presented to you.

First of all, you have been given an equation representing an expression for motor horsepower in terms of calender stack variables that can be measured. In other words, it is possible now to calculate the horsepower required to drive a supercalender. You may say in rebuttal that you already know how much horsepower is required to drive your calender stacks. That is, you can put a wattmeter on the motor that drives the stack and determine this quickly. True, but the real advantage in having an equation like this one becomes apparent when it is necessary to project or design an entirely new or different stack.

When one has an engineering "scaling" operation to perform, such an equation is extremely valuable. At such a time it is not only reassuring to know that the equation is available, but that there is quite a bit of experimental evidence available to you to demonstrate its validity.

Now, admittedly, as has been stated by a previous speaker in this conference, the fact that a theoretical development seemingly leads to the right answer is a necessary but not sufficient condition to guarantee validity of the theory. Nevertheless, being a pragmatist, myself, and being concerned simply with whether a thing will or won't "work," I recognize herein a theoretical development that has been well substantiated by a considerable amount of data, not all of which has been presented in this paper, as I understand.

The second package given to you in this paper is an equation describing the radial temperature distribution through the thickness of roll filling. As any one who has worked very long around supercalenders knows, it is possible to develop a burn-out or blow-out in a roll filling when the load and speed conditions of the stack are unfavorable. This equation, which unfortunately does not appear to be backed by as much experimental data as the one relating to horsepower, nevertheless does give us some concept as to why and how a locale of maximum temperature is created through heat development in the roll filling.

I might add, at this point, that it would be wonderful to have a needle thermocouple so rigidly built that one could jab it into these roll fillings and measure temperature as a function of radius. I know of none, however.

At this point in the discussion I want to admit that the authors and I have, in a sense, stacked the cards against the audience, in that we wish to direct to you a few questions that we hope will stimulate some thought and questions on your part. I am directing the first two of these questions particularly to the high concentration of physicists that I see in the audience.

First, "Does this theory suggest to you a means of determining whether plastic or other uncommon types of roll fillings might offer favorable roll life or power dissipation advantages?"

Second, "Does the theory provide explicitly or implicitly for any slippage between roll surfaces within the confines of the nip region?" This is a matter that is pertinent, of course, to a consideration of gloss or smoothness development in the surface of the calendered paper, which matter the Malmstrom-Nash paper does not consider. Nevertheless, I consider it a good subject for speculation.

The third question is directed at the machine builders and others present who may have had experience with power consumption by supercalender stacks. Do you have independent data that will support or refute the "$^3/_2$-power" law regarding power dissipation as a function of nip loading?

Now, of course, it would not do to let the authors escape without any questions whatsoever, and so I'd like to turn attention now to a few that I will direct to Mr. Malmstrom. I have a rather long list, but in the interest of conserving valuable time, I will not go into all of them. However, I will select a few which I think will be of major interest to the audience. The first one is as follows:

The power calculations given in your paper neglect any consideration of the power loss in plastic deformation of a web of paper. If one of us were to build a new stack, we might on occasion like to run some paper through it.

MALMSTROM: I think that I had better answer these as they come.

The power calculations we presented dealt only with the supercalender stack itself. The extra power required de-

pends on the basis weight of the paper. Now, to the calculated figures, at least on the light papers, such as the 40-lb. book, you must add something like 15 to 17% of the power. If you have a heavy-weight paper, you should add 25 to 28% more than the calculated power to run the stack with the paper in it.

I think that this should satisfy that question.

GREISHEIMER: The second question is this: It occurs to me that it might just be possible by way of getting further evidence and support of the accuracy of the power equation to conduct a heat balance—in other words, you put so much horsepower into the driving of the stack. Now, this loss must necessarily appear as heat and some of this heat, of course, is going to be used in raising the temperature of the web of the paper. We know that there is a certain amount of moisture loss by evaporation so that there is a latent heat of vaporization that must be provided. I am told that radiation losses and convection losses might also be a factor in this picture and I wonder if you have at any time tried to look at this from the viewpoint of trying to make such a heat balance?

MALMSTROM: In a very crude sort of way, yes. If you will notice where it shows the calender stack, Fig. 5, that the horsepower per square inch is the average horsepower; 1.3 hp. per in., at a speed of 1000 f.p.m. There is a middle nip loading of 2500 lb. per in.—1.3 hp. per in. That is multiplied by three-quarters in order to convert it into kilowatts. One gets 1 kw. Roughly, that is equal to 1 B.t.u. per sec. Now, 1 B.t.u. per sec. is the average power delivered to the stack. To this must be added about $^1/_4$ of a B.t.u. per sec. because of running the sheet. So the total power is about 1.25 B.t.u. per sec. or 75 B.t.u. per min.

Now, all of that heat must be carried away by the stack of paper—by the sheet of paper, or otherwise that stack would continue going up in temperature and pretty soon it would disperse like an atomic bomb. Therefore, all of the heat is carried away by the paper.

Now, the paper that comes off the paper machine, as it is taken over to the stack, is fairly warm. The temperature could be 100°F. When it comes out of the stack it is in the range of from 170 to 180°F. It cannot get much hotter for then water will flash off, cooling the sheet. Therefore, that paper is heated up some 70°.

Some water is evaporated, roughly somewhere between a half and 1%. Let's pick 1% as being fairly representative. Now, on a 1-in. wide sheet, running 1000 f.p.m., that strip is 1000 ft. long. That is about 80 sq. ft. of paper per min. and on a 3000-sq. ft. ream, is about $^1/_{40}$ of a ream.

Now, say that we are running a 40-lb. sheet—2 lb. of paper are going through 1 in. of the nip per min., 1% moisture and then 0.02 lb. of water are evaporated. At 1000 B.t.u.'s per lb. 20 B.t.u.'s are being evaporated per min.

The sheet is being heated up some 70°. Since the specific heat of paper is probably close to 0.3 B.t.u.'s per lb. per degree Fahrenheit, the heat used to heat the paper is 2 lb. × 0.3 × 70 = 42 B.t.u. per min. Add to this 20 B.t.u. for evaporation of water, the total becomes 62 B.t.u. per min. as compared with the 75 B.t.u. per min. input.

In order to strike a good heat balance one would have to do it much more carefully than I did here.

LEONARD PARKINSON (Rhinelander Paper Co.): Mr. Malmstrom, do you neglect the number of rolls?

MALMSTROM: No, if you will notice Fig. 5, the summation of those terms, you add up the contribution on to each nip, so that the top nip, each paper roll, has two nips, of course, and that contribution only is added up for the total stack.

N. SHOUMATOFF (West Virginia Pulp & Paper Co.): Mr. Malmstrom, in his study of power and heat in supercalender rolls, has given us a dazzling demonstration of the power of mathematical analysis. It is unfortunate that the brilliant verbal introduction to his presentation will apparently not be included in the record. His remark that the previous papers had assured the production of a perfectly uniform sheet on the fourdrinier and its delivery in that condition through the presses and drier section and had solved all the problems of papermaking except calculating the power of a supercalender, served as a somewhat ironic summary of the symposium and at the same time a challenge for future work. It may be of interest to mention briefly that a few other problems remain to be solved with particular reference to supercalenders.

Throughout his analysis, Mr. Malmstrom assumed that power and heat generation are constant per inch of roll face. The naturalness of this assumption on his part is a tribute to the perfect mechanical condition of the supercalenders with which he is most familiar. For the benefit of less fortunate calender operators it would be of interest to introduce the effects of deflection and crowning of the rolls into the calculations of heat and power. Furthermore, the calculation of crowns as a function of roll diameters and arrangement of the supercalender, and the influence of the number of nips, size of rolls, width and pressure at the nip on the production of gloss, is a wide field for mathematical study. Use of air and water for cooling the rolls provides a wide field for heat transfer studies in the operation of high-speed supercalenders.

Closely associated with the supercalender is the rewinder and a mathematical study of roll hardness as a function of sheet tension, roll radius, and uniformity of caliper would be highly desirable. Here again Mr. Malmstrom might wish to use Bessel functions. It is appropriate that these functions characteristically concerned with cylindrical coordinates have at least been mentioned in this symposium, since the paper machine is so largely a collection of cylinders.

Finally, Mr. Malmstrom's unusual skill in transformation of complicated equations to simple forms might also suggest possibilities for simplification of the papermaking process itself. Perhaps the ideal would be the description by a young girl who said that to make paper you simply chop up the wood, cook it, and wind it up on rolls.

I have no doubt that Mr. Malmstrom's power of analysis will lead to future useful results in some of the problems indicated above. I am equally sure that any papermaker could indefinitely extend the list of problems left to be solved.

VAN DER MEER: To calculate the power consumed by a supercalender stack you must first know how much head is required to get the wanted finish. How is that calculated, especially what is the influence of the roll diameter?

Other things being equal the diameters of the rolls in a supercalender stack, the fiber-filled rolls, and the intermediate steel rolls, have little or no influence on the resulting finish.

In our experimental supercalender we have compared the supering action of the following nips:

3-in. diam. steel roll — 8-in. diam. fiber roll
3-in. diam. steel roll — 14-in. diam. fiber roll
3-in. diam. steel roll — 24-in. diam. fiber roll
10-in. diam. steel roll — 8-in. diam. fiber roll
10-in. diam. steel roll — 14-in. diam. fiber roll
10-in. diam. steel roll — 24-in. diam. fiber roll
24-in. diam. steel roll — 8-in. diam. fiber roll
24-in. diam. steel roll — 14-in. diam. fiber roll
24-in. diam. steel roll — 24-in. diam. fiber roll

The results of this work form the basis of the above statement.

The nip loading required to get a given finish is known from experience on other operating stacks.

MODERATOR WOLLWAGE: I would like to turn the meeting over to one of our co-chairmen. I believe Mr. Logan of our Canadian committee is already on his way home from the meeting. He had to leave early, so, Mr. Lewis, will you take over.

LEWIS: Ken opened it up and I'll close it.We are certainly glad that you are here and we hope that you have enjoyed it. We will try to get the discussions into good shape for you so that they may be read later together with the papers which were presented.

The Alkali Resistance of the Pentosans in Aspenwood

JAMES R. SCHOETTLER

An individual aspenwood was used in this study and all holocellulose preparations and bleaching operations entailed the use of acidified technical sodium chlorite. Alpha-celluloses containing 8 to 9% of xylan resistant to extraction by 17.5% NaOH (termed *resistant xylan*) were prepared from a bleached kraft pulp. Alpha-cellulose isolated from holocellulose retained only about 2% xylan. Hydrolysis and paper partition chromatography showed that the higher pentosan content of the kraft pulp alpha-cellulose determined analytically was due definitely to xylose units. The difference in the resistant xylan content of the two types of alpha-cellulose from the same wood formed the basis for this investigation. The resistant xylan content of the kraft pulp could not be reduced even on drastic bleaching. Alkali-resistant "xylan" was not formed from cellulose during a kraft cook and the alkali resistance of the xylan in a chlorite holocellulose was not increased by subsequent kraft cooking. High-yield, low-lignin content pulps were produced from chips and shavings by alkaline pretreatment at room temperature, followed by chlorite delignification at room temperature. Even after hot bleaching at 70 to 80°C., these so-called "aspen chlorite pulps" contained appreciable amounts of xylan unextractable by 17.5% NaOH. Alkaline pretreatment, however, was essential to give this result. However, the same treatments applied to wood meal produced products much lower in resistant xylan than chips or shavings. Potassium hydroxide removed much more xylan from bleached kraft pulps than did equivalent concentrations of sodium hydroxide, and 17.5% NaOH proved perhaps the least satisfactory means of dissolving xylan. A method was developed for isolating a relatively pure xylan from the bleached pulp, by first extracting with 17.5% NaOH, air drying, extracting further with 24% KOH, and recovering the xylan from this second alkaline solution. The resistance of xylan to alkali extraction was due in part to the physical structure of the fiber. Fragmentation of the fiber permitted more xylan removal. The alpha-cellulose from an unbeaten pulp retained more xylan than a pulp which was first beaten. The alpha-cellulose from dried pulp retained more xylan than did that prepared from moist pulp.

ASPEN hemicelluloses may actually contain as much as 65 to 70% xylan. The term "hemicellulose" was first applied by Schulze (*1*) to the cell wall components of plant materials which are hydrolyzed to simple sugars by hot dilute mineral acids and which are dissolved by hot dilute alkalies. Today this term is also used to designate the polysaccharides extractable from a wood holocellulose by means of cold concentrated alkalies. Papers by Wise (*2–4*) and chapters by Whistler (*5*) and Hägglund (*6*) serve to summarize adequately much of the present-day knowledge on the hemicelluloses of wood.

Pentosans, being readily hydrolyzed by hot dilute mineral acids, are, by one definition at least, a part of the hemicelluloses. However, a certain portion of the xylan in aspenwood remains in the analytically defined alpha-cellulose fraction. In hardwood kraft pulps, a very appreciable part of the total xylan is resistant to alkaline extraction. This resistant xylan (according to Schulze's classical definition) would not be part of the hemicellulose fraction but would belong to the alpha-cellulose. Thus, it is difficult to state clearly just where an alpha-cellulose ends and a hemicellulose begins.

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PRESENTATION OF PROBLEM

A study was made of the factors and conditions affecting the resistance of aspenwood pentosans to cold alkaline extraction. This included the various methods for preparing the wood samples, the kraft pulping procedures, the holocellulose preparation, bleaching, etc.; and also the conditions for the alkaline extraction itself.

As originally conceived, the problem was much narrower. It resulted from the observation by March (*7*) that there was a difference between the resistance to alkaline extraction of pentosans in a bleached kraft pulp and that of the pentosans in a chlorite holocellulose. The former gave an alpha-cellulose containing 8.9% pentosans, whereas the latter gave an alpha-cellulose with only 1.2% pentosans. These results are paradoxical; the sodium chlorite delignification procedure is generally considered mild in its action on carbohydrate material, whereas the kraft process is relatively drastic. This paradox stimulated the present study.

HISTORICAL REVIEW

The resistance of pentosans to alkaline pulp purification has received attention because of its industrial importance to the dissolving pulp industry. Highly purified alpha pulps low in pentosans are required in the viscose, acetylation, and nitration processes.

Hardwood soda or kraft pulps, although more difficult to purify, may offer two important advantages over the softwood sulphite pulps which are now in general use. The hardwoods represent a great source of raw material. Alkaline digestion yields pulps with much more uniform molecular weight distributions than does the sulphite process. This has spurred interest in the so-called resistant pentosans and their removal by various purification procedures. For example, hydrolysis followed by alkaline cooking has led to the removal of pentosans and better purification of hardwood pulps.

The work of various investigators that has shed some light on the problem of alkali-resistant pentosans includes that of Schmidt and his co-workers (*8*), Jayme (*9*), Astbury, Preston, and Norman (*10*), Norman (*11, 13, 14*), Sisson (*12*), Meyer (*15*), Klingstedt (*16*), Lindpainter (*17*), Dolmetsch, Franz, and Correns (*18*),

Campbell and Booth (*19*), Mackney (*20*), McKinney (*21*), and Meller (*22*).

Meller (*22*) found that drying at 105°C. increased the resistant pentosan content of pulps, whereas beating in a Lampén mill reduced it. He defined resistant pentosans as those remaining in the pulp after two extractions with cold 6.5% NaOH which exerted the greatest dissolving power on pentosans.

EXPERIMENTAL PROCEDURES

Preparation and Analysis of Raw Material

The wood used was obtained from an aspen tree (*Populus tremuloides*) $6^1/_2$ in. in diameter. The wood was in part converted into chips and in part into wood meal. The chips were air dried and screened. The meal passing a 30-mesh screen but retained on a 50-mesh screen (30 to 50-mesh fraction) was saved for the bulk of the experimental work. More wood meal of various desired mesh sizes was obtained from the chip supply.

The 30 to 50-mesh wood meal was analyzed by TAPPI Standards, using the extractive-free wood meal excepting in the case of uronic anhydride which was determined by Browning's method (*23*). The results are given in Table I.

Cooking and Bleaching Procedures

Kraft cooks were made using chips, holocellulose, and alpha-cellulose, as well as cotton linters, each in a 4-liter stainless steel digester equipped with pressure gage, thermometer well, and relief valve. The digester was heated in a wax bath using two Meker blast burners. The cooking liquors were invariably prepared from pure chemicals and distilled water. However, a technical grade of sodium chlorite was always used in preparing holocellulose or in bleaching. The cooked chips were dumped into a cloth wash box, washed with warm water, and defibered in a Williams disintegrator. All pulps were washed free of liquor with warm water, pressed, air dried, and stored in moisture-tight bottles

Table I. Analysis of Trembling Aspenwood Meal

	Extractive-free basis, %	*Unextracted basis, %*
Alcohol extractives	...	3.2
Water extractives	...	1.0
Total extractives	...	4.2
Lignin	16.4	15.7
Alpha-cellulose[a]	53.9	51.6
Uronic anhydride	4.7	4.5
Pentosans[b]	19.1	18.3
Ash	0.4	0.4

[a] Not corrected for pentosan.
[b] Calculated as xylan and corrected for hydroxymethylfurfural and uronic anhydride.

Holocellulose preparations were made by the method of Wise, Murphy, and D'Addieco (*24*), using air-dried unextracted materials.

Prior to bleaching, the air-dry pulps were Abbé milled. The standard procedure adopted was a 1-hr. treatment using chlorite as in the holocellulose procedure.

Alpha-Cellulose Preparations

Alpha-celluloses were prepared prior to the determination of resistant pentosans. Except in the alkali-concentration studies described later, all resistant pentosans of a pulp or holocellulose were defined as those insoluble in sodium hydroxide, using TAPPI Standard T 203 m-44 (no attempt was made to obtain a carbonate-free alkali). Ten-gram samples of pulp were used with a proportionate increase in the amount of alkali. The same method and proportions were also used to obtain larger batches of alpha-cellulose. The preparations were invariably air dried. However, one large batch of alpha-cellulose, which was later subjected to a kraft cook, was prepared from 30 to 50-mesh holocellulose using a 2-hr. extraction at room temperature with 16% KOH (*24*).

Xylan—Isolation and Analyses

This was carried out by pouring the alkaline filtrate of a holocellulose or pulp into 4 to 5 volumes of ethyl alcohol containing an excess of glacial acetic acid. After the xylan had settled, the supernatant liquor was siphoned off and the material was centrifuged, washed with alcohol and ether, and dried *in vacuo* at 50°C.

TAPPI Standard T 223 m-48 was used, but the results were calculated as xylan and the correction factor for hydroxymethylfurfural of 0.9% was subtracted from all the results obtained in the cellulose analyses. No correction was applied, however, when the isolated xylan fractions were analyzed.

Hydrolysis Procedures

Certain of the alpha-celluloses and the xylan fractions were hydrolyzed to their constituent sugars and analyzed qualitatively by means of paper partition chromatography (*25*, *26*).

The hydrolysis procedure first used was essentially that of TAPPI Standard T 222 m-49 for lignin with the following modifications. The diluted sulphuric acid suspension was neutralized with barium carbonate paste, boiled to expel carbon dioxide, filtered, made slightly acidic with acetic acid, and concentrated *in vacuo* to a sirup, which was then developed on a paper partition chromatogram using butanol-ethanol-water or ethyl acetate-acetic acid-water as the developer.

Later, an unpublished method of Jones (*27*) was used and the neutralization and concentration steps were omitted. The acidic solution was spotted directly on the paper chromatogram where it was concentrated by placing an appropriate number of drops on the same spot and allowing the water to evaporate between each drop. The chromatogram was then developed in butanol-pyridine-water. The pyridine formed a pyridinium salt which remained near the top of the paper and the sugars developed in the normal manner as though they had been spotted on the paper from a *neutral* solution.

Preparation of "Chlorite Pulps"

A small-scale pulping procedure was used in producing pulps high in resistant xylan content from aspen chips or shavings. It consisted of an alkaline treatment prior to delignification with acidified chlorite at room temperature. All pulps prepared by this process or modifications thereof have been termed, for convenience, "chlorite pulps" to distinguish them from kraft pulp.

One hundred grams of air-dried chips of known mois-

ture content were soaked in 1000 ml. of 17.5% NaOH with occasional stirring for 24 hr. The chips were then filtered on a 150-mesh stainless steel wire screen in a Buchner funnel, washed with water, soaked in fresh distilled water for 1 hr., and refiltered. They were then soaked in 3000 ml. of 5% acetic acid for 4 hr., filtered, washed, and transferred to a 4-liter beaker containing 2000 ml. of distilled water. Delignification was then effected by adding 50 ml. of glacial acetic acid and 100 grams of sodium chlorite and allowing the reaction to take place for 48 hr. in a covered beaker at room temperature, with occasional stirring. When no alkaline pretreatment was given, no appreciable softening of the chips occurred, even after 1 to 2 weeks. Alkaline pretreatment was therefore essential to ensure penetration of the chlorite liquor.

Subsequently the chips were filtered on the stainless steel wire and were washed several times before being removed from the hood in which chloritings always took place. The partially washed chips were defibered by passage through a laboratory Bauer refiner, or by stirring batchwise in a British disintegrator. The pulp fibers were then refiltered on the fine stainless steel screen, washed successively with distilled water and acetone, air dried, and stored in a tightly sealed bottle from which samples were removed for subsequent analyses.

Shavings prepared on a power planer were converted into chlorite pulps by a very similar procedure. Fifty grams of shavings were pretreated 4 hr. with 1000 ml. of 17.5% NaOH. After washing and acidification, the treated shavings were delignified at room temperature in 1200 ml. of water, using 25 ml. of glacial acetic acid and 50 grams of sodium chlorite. A 24-hr. reaction period was found ample in pulping the shavings; 48 hr. were required for the chips.

PRESENTATION AND DISCUSSION OF DATA

Preliminary Investigations

March's results (7) were verified both in small-scale and large-scale experiments. Kraft cook 1 was carried out with 600 grams of aspen chips, using the conditions described by March. Table V gives a summary of this cook. A 30-gram sample of the pulp was bleached, also using the mild conditions described by March. Holocellulose was prepared (in 82% yield) from 50 grams of the air-dried, unextracted, 30–50-mesh aspenwood meal by the standard procedure.

The bleached pulp and the chlorite holocellulose were converted into the respective alpha-celluloses by extraction with 17.5% NaOH and each alpha-cellulose was analyzed for xylan by the usual method. The results are given in Table II.

The large-scale preparations of alpha-cellulose were also carried out to provide sufficient material for further experimentation. Chlorite holocellulose was prepared batchwise from a total of 1350 grams of 30–50-mesh wood meal, and 650 grams of this air-dried material were converted into alpha-cellulose by extraction with 16% KOH. Subsequently, 260 grams of the kraft pulp were bleached by the standard procedure and air dried; a 50-gram sample of the bleached pulp was converted into alpha-cellulose. These two alpha-celluloses were analyzed for xylan (Table II).

These data corroborate those of March, although the magnitude of the difference in alkali-resistant xylan was not quite as great as that obtained by him.

Hydrolysis of Alpha-Celluloses

In order to determine whether the greater furfural yield from the kraft pulp alpha-cellulose was due specifically to a greater xylan content, samples of the alpha-celluloses were hydrolyzed and analyzed for their constituent sugars by means of paper partition chromatography. Four grams each of the alpha-cellulose from chlorite holocellulose (containing 2.3% xylan) and of the alpha-cellulose from the bleached kraft pulp (containing 8.5% xylan) were hydrolyzed by the standard procedure. The final sirups were adjusted to equal volumes, spotted on Whatman no. 1 filter paper strips, and chromatographed with butanol-ethanol-water as the developer.

Table II. Comparison of Alpha-Celluloses

	Resistant xylan contents of alpha-celluloses, %[a]	
	From chlorite holocellulose	*From bleached kraft pulp*
Data obtained by March (7)	1.2	8.9
Small-scale preparation	2.3	8.5
Large-scale preparation	2.0	8.1

[a] Based on the alpha-cellulose.

The sirup from the alpha-cellulose containing 2.3% xylan by analysis gave a heavy glucose spot and a very weak xylose spot. The sirup from the kraft pulp alpha-cellulose containing 8.5% xylan gave a heavy glucose spot and a fairly heavy xylose spot. These experiments qualitatively established that the higher furfural yield from the kraft pulp alpha-cellulose was actually due to a higher xylan content (and not simply to other "furfural-yielding material").

Overbleaching of Kraft Pulp and Kraft Pulp Alpha-Cellulose

To determine whether drastic chloriting conditions in the holocellulose procedure might be responsible for the low resistant xylan content, samples of the unbleached kraft pulps and of the kraft alpha-cellulose from the large-scale preparation were deliberately overbleached.

Table III. Effect of Overbleaching and Re-extraction on Resistant Xylan

	Alpha-celluloses from		
	Overbleached kraft pulp	*Kraft alpha-cellulose*	*Overbleached kraft alpha-cellulose*
Xylan content prior to bleaching, %	16.1	8.1	8.1
Hours of chlorite treatments	2	0	1
Bleaching yield, %	96.2	..	98.2
Xylan content after bleaching, %	16.4	..	8.0
Alpha-cellulose content (based on material extracted), %	87.8	97.6	97.8
Resistant xylan content, %	8.1	6.9	5.8

The kraft pulp was given a 2-hr. bleach by the standard chlorite procedure and the kraft alpha-cellulose was given a 1-hr. bleach. These two bleached products and another sample of the alpha-cellulose (cf. Table II) from a mildly bleached pulp, were then extracted with

17.5% NaOH by the standard procedure, and the xylan contents of the bleached products and of the three alpha-celluloses were determined. These results are given in Table III.

Obviously, the strong bleaching conditions have no specific effect on the resistant xylan content. Mild bleaching and very strong bleaching both produced alpha-celluloses with about 8% resistant xylan. Furthermore, although bleaching the alpha-cellulose prior to a second alkaline extraction decreases the resistant xylan content from that obtained without bleaching, neither value (5.9 or 6.9%) approaches the low values obtained for alpha-celluloses prepared from holocellulose (i.e., 2.0 to 2.4%). Drastic sodium chlorite treatment does not exert a serious degrading influence on the alkali-resistant xylan in the kraft pulp.

Kraft Cooks on Holocellulose, Alpha-Cellulose, and Cotton Linters

Kraft cooks 2, 3, and 4 were made with 200 grams each of the holocellulose, the alpha-cellulose therefrom, and cotton linters, respectively. The purpose of the holocellulose cook was to determine the effect of the kraft conditions on the xylan as it exists in the holocellulose. Alpha-cellulose and cotton linters were cooked to explore the remote possibility that cellulose might be converted to resistant xylan. The cooked holocellulose was analyzed for alpha-cellulose and resistant xylan. The cooked alpha-cellulose and cotton linters were analyzed directly for xylan. The "xylan" values shown for cotton linters are those actually obtained by titration and are uncorrected. Direct comparison with the other values may be made assuming that the cotton linters value was zero. These data are given in Table IV; the cooking conditions are shown in Table V.

Table IV. Results of Kraft Cooks 2, 3, and 4

	Material cooked		
	Holocellulose	*Alpha-cellulose*	*Cotton linters*
Yield of product (based on material cooked), %	61.9	82.3	86.0
Yield of product (based on original wood), %	52.6	42.6	..
Xylan content of material cooked, %	21.6	2.0	0.8
Xylan content of product, %	17.8	1.0	0.4
Alpha-cellulose content (based on product), %	77.2	..	97.3
Alpha-cellulose yield (based on original wood), %	40.6	..	..
Resistant xylan content, %	1.6	..	..

Neither alpha-cellulose nor cotton linters showed an increase in xylan content after a sulphate digestion. Hence, xylan is not generated from cellulose during a kraft cook.

Although the xylan content of the kraft-cooked holocellulose was slightly higher than that of a normal kraft pulp, most of it was shown to be alkali soluble. Hence, a kraft cook does not increase the alkali resistance of xylan as it exists in chlorite holocellulose.

Sodium Chlorite Delignification of Aspen Chips and Shavings

Cold alkaline pretreatment of aspen chips, followed by delignification with an excess of acidified sodium chlorite at room temperature, yielded pulps with a high resistant xylan content. This xylan was also shown to be very resistant to strong bleaching and to a second alkaline extraction. These pulps apparently resemble alkaline cooked pulps with respect to resistant xylan.

Table V. Cooking Conditions for Kraft Cooks

	Cook no.			
Material cooked →	*1 Wood chips*	*2 Holocellulose*	*3 Alpha-cellulose*	*4 Cotton linters*
Active alkali, %	24	24	24	30
Sulphidity, %	33.3	33.3	33.3	33.3
Water: material ratio	5.5:1	8:1	8:1	12:1
Time to 100°C., min.	30	15	15	10
Time, 100–176°C., min.	50	45	45	45
Max. temp., °C.	176	176	176	176
Time at max. temp., min.	45	30	30	45
Time to relieve to zero pressure, min.	10	5	5	5
Actual cooking time, min.	105	80	80	95

Chlorite pulp 1 was prepared according to the method described in the section on Experimental Procedures. After air drying, a sample was bleached for 1 hr., using the standard holocellulose procedure, after which the air-dried, bleached pulp was converted into alpha-cellulose. A second sample was first extracted with 17.5% NaOH by the alpha-cellulose procedure, air dried, and then bleached for 1 hr. by the standard procedure. This air-dried, bleached alpha-cellulose was then re-extracted with alkali to determine the resistance of the xylan to a second alkaline extraction. The results of these experiments are presented in Table VI.

Table VI. Results of Cold Chlorite Delignification of Alkaline-Treated Chips

Unbleached pulp yield (chlorite pulp 1), %	70.1
Bleached pulp yield, %	64.3
Alpha-cellulose yield (based on original wood), %	54.4
Resistant xylan content, %	10.9
Alpha-cellulose yield (after bleaching and re-extraction), %	50.7
Resistant xylan content, %	9.5

Even after a full hour bleach of the pulp, the alpha-cellulose yield was still 54.4% of the original wood and the xylan content was 10.9%. This is higher than the results obtained for the chemical kraft pulps but the reason for the high xylan content presumably is similar. After a second alkaline extraction, the xylan content was 9.5%, a value similar to those obtained for the alpha-celluloses from the kraft pulps.

The effect of the temperature of chlorite delignification of alkali-treated chips was indicated by repeating the above experiment, using a higher temperature during chlorite treatment after the alkaline pretreatment. Chlorite pulp 2 was from chips which were treated with 17.5% NaOH by the standard procedure, washed, delignified by a 4-hr. treatment using the standard holocellulose procedure (at 70 to 80°C.), and finally washed and pulped by the usual method. A

sample of the pulp was then converted into alpha-cellulose and the resistant xylan determined (Table VII).

When the sequence of the preceding experiment was reversed, it was found that alkaline treatment prior to chlorite delignification is an important factor in the retention of alkali-resistant xylan. Small aspen chips were used to promote penetration of the hot chlorite liquor. One hundred grams of these chips were soaked overnight in water and then chlorited at 70 to 80°C. However, the third and fourth additions of sodium chlorite entailed 2 hr. each because penetration was slow. After cooling to room temperature, the chips were filtered, diffused in water for 3 hr., refiltered, extracted with 1000-ml. of 17.5% NaOH for 10 hr., filtered, washed, and pulped by the usual procedure. The yield of pulp was 48.6%. Its resistant xylan content was only 3.7%, thus showing the necessity of the proper sequence of treatments in order to retain resistant xylan. Obviously, the alkaline treatment must precede the sodium chlorite delignification.

Table VII. Results of Hot Chlorite Delignification of Alkali-Treated Chips

Pulp yield, %	65.4
Xylan content of pulp, %	19.7
Alpha-cellulose content (based on the pulp), %	79.6
Alpha-cellulose content (based on original wood), %	52.1
Resistant xylan content, %	9.2

Because of penetration difficulties, shavings were later substituted for chips. Several batches of shavings were carried through a chlorite pulping procedure similar to that used for the chips. Alpha-celluloses with resistant xylan contents of 13.5 and 13.0% were obtained; thereafter, shavings were substituted for chips in this procedure, thus circumventing a penetration problem.

However, when some of these same shavings were prechlorited by the standard holocellulose procedure (at 70 to 80°C.), converted into a rather harsh pulp in the small Bauer refiner, air dried, and subsequently converted into alpha-cellulose by the standard procedure, the resistant xylan content dropped to 2.6%. This substantiated the importance of an alkaline pretreatment in obtaining alpha-celluloses high in resistant xylan.

Cold chlorite treatment of shavings for 5 days, followed by conversion to alpha-cellulose, gave an alpha-cellulose yield of 50.6% with a resistant xylan content of 4.5%. Thus, the temperature of chloriting played a relatively minor role in the amount of resistant xylan retained in a pulp.

Chlorite Pulping Procedure Applied to Wood Meal

The above experiments were also repeated with wood meal. If the resistant xylan was actually formed by some chemical reaction during alkaline pretreatment, this same reaction should obtain when wood meal was treated with alkali.

Wood meal was extracted with 17.5% NaOH for 4 hr. at room temperature. After filtering and washing, the material was air dried. The (dry) yield was 78.6% with a xylan content of 11.7%. This material was treated with sodium chlorite at room temperature. Separate batches, however, stood for periods of 2, 4, and 6 days. The results are given in Table VIII.

Although 4 days were required for complete chloriting, a 2-day period produced sufficient delignification to give a relatively high alpha-cellulose yield. This is the same time period as that used satisfactorily for alkali-treated chips. However, the resistant xylan content of 5.1% is much lower than that found in the alpha-celluloses from chlorite pulping of chips and shavings, respectively (i.e., 10.9 and 13.5%).

Thus, resistant xylan cannot be attributed entirely to a chemical reaction during alkaline pretreatment or alkaline pulping of chips. The cause appears to be related to certain differences between wood chips and wood meal; one explanation might be an increase in physical availability of the xylan to alkaline extraction caused by fineness of division of the meal.

Table VIII. Chlorite Pulping of Wood Meal

	2 Days	*4 Days*	*6 Days*
"Pulp" yield (based on extracted meal), %	80.5	75.8	75.5
"Pulp" yield (based on original wood), %	63.2	59.6	59.3
Alpha-cellulose content (based on "pulp"), %	80.2	82.0	82.6
Alpha-cellulose yield (based on original wood), %	50.8	48.9	48.9
Resistant xylan content of pulp, %	5.1	4.0	3.8

Subsequently, a batch of the wood meal was treated directly with acidified sodium chlorite at room temperature for 4 days. The holocellulose thus obtained was converted into alpha-cellulose by the standard procedure and analyzed for resistant xylan. The alpha-cellulose yield was 51.1% and the resistant xylan content was 4.3%, which is almost identical with that of the resistant xylan obtained after alkaline pretreatment of wood meal (Table VIII). Obviously, alkaline pretreatment has little effect on the resistant xylan content of alpha-celluloses prepared from wood meal.

Effect of Type of Alkali and Concentration on Resistant Xylan

Comparison of 17.5% Sodium Hydroxide and 16% Potassium Hydroxide. A marked difference was shown between the xylan-extractive power of 16% KOH and that of 17.5% NaOH. Potassium hydroxide seemed able to extract much more xylan, leaving an alpha-cellulose residue with a relatively low resistant xylan content.

Table IX. Alpha-Celluloses from Bleached Kraft Pulp

	16% KOH[a] A	*16% KOH[a] B*	*17.5% NaOH[a] A*	*17.5% NaOH[a] B*
Alpha-cellulose content (based on pulp), %	87.2	87.0	91.5	91.6
Alpha-cellulose yield (based on original wood), %	45.9	45.8	48.2	48.2
Resistant xylan content, %	4.9	4.7	9.2	9.6
Resistant xylan content (based on bleached kraft pulp), %	4.27	4.17	8.42	8.78

[a] A with, and B without dilution before filtration.

A large batch of bleached kraft pulp was prepared from the unbleached pulp by a 1-hr. bleach according to the standard procedure. Four alpha-celluloses were

prepared therefrom, one of each with dilution and one of each without dilution prior to filtration, using potassium and sodium hydroxides. The results obtained are shown in Table IX.

The air-dry kraft pulp alpha-cellulose (large-scale preparation) containing 8.1% xylan and an air-dry chlorite pulp alpha-cellulose containing 10.9% xylan were re-extracted with the two alkalies by the standard procedure. Dilution was used prior to filtration. These data are presented in Table X.

Table X. Re-extraction of Alpha-Celluloses with KOH and NaOH

	Alpha-cellulose from			
	Kraft pulp		*Chlorite pulp*	
	16% KOH	*17.5% NaOH*	*16% KOH*	*17.5% NaOH*
Alpha-cellulose content (based on original alpha), %	95.3	98.6	88.6	92.6
Alpha-cellulose yield (based on original wood), %	44.0	45.6	48.2	50.4
Resistant xylan content, %	3.7	6.5	2.8	7.4
Resistant xylan content (based on original alpha), %	3.51	6.41	2.48	6.85

The data of Tables IX and X indicate that, irrespective of whether or not the extraction mixture is diluted prior to filtration, 16% KOH is far more effective in its removal of xylan than is 17.5% NaOH. Potassium hydroxide gives lower yields of alpha-cellulose and this, in turn, contains less xylan. Using the data of Tables IX and X, it can be shown that 16% KOH is more effective in xylan removal by a tabulation of the difference in yield and the difference in resistant xylan content obtained in the case of 17.5% NaOH on the one hand and 16% KOH on the other. These results are shown in Table XI.

These calculations show that, in each case, all the additional material removed by 16% KOH was approximately accounted for as xylan.

Another calculation was made from the data of Table XI. The yield on extraction of the kraft pulp alpha-cellulose with 16% KOH was 95.3%, indicating a total loss of 4.7 grams per 100 grams of alpha-cellulose. The xylan content of the alpha-cellulose before extraction was 8.1% but after extraction it was only 3.7%. The xylan loss was 8.1 -0.953×3.7 or 4.6 grams. Therefore, practically all the material extracted was accounted for as xylan. This calculation formed the basis of a later experiment.

Table XI. Comparison of Yield and Xylan Differences Using 16% KOH and 17.5% NaOH

Alpha-cellulose from	*Yield difference, g.*[a]	*Xylan difference, g.*[a]
Bleached kraft pulp (with dilution)	4.3	4.15
Bleached kraft pulp (without dilution)	4.6	4.61
Kraft pulp alpha-cellulose	3.3	2.9
Chlorite pulp alpha-cellulose	4.0	4.37

[a] Based on 100 grams of original alpha-cellulose.

Effect of Concentration of Alkali on Resistant Xylan Content. A large batch of "chlorite pulp" was prepared from wood chips by the standard procedure. The unbleached pulp yield was 66.9%. This pulp was air dried, bleached by the standard procedure, again air dried, and Abbé milled. The bleached pulp yield was 61.5% based on the original wood ($0.669 \times 92\%$ bleaching yield) and its xylan content was 17.3%.

The alkali concentrations used (percentage by weight) and the molarities are shown below:

NaOH concentration, %	6	11.7	17.5	24
Molarity	1.60	3.30	5.20	7.57
KOH concentration, %	8	16	24	32
Molarity	1.53	3.28	5.26	7.48

The results of the experiments are given in Table XII.

Table XII. Concentration Studies on Aspen Chlorite Pulp

Part A				
NaOH concentration, %	6	11.7	17.5	24
Alpha-cellulose content (based on bleached pulp), %	80.6	81.6	83.6	83.4
Alpha-cellulose yield (based on original wood), %	49.6	50.2	51.4	51.3
Resistant xylan content, %	4.1	6.1	8.1	7.0
Part B				
KOH concentration, %	8	16	24	32
Alpha-cellulose content (based on bleached pulp), %	81.3	81.3	79.6	79.8
Alpha-cellulose yield (based on original wood), %	50.0	50.0	49.0	49.1
Resistant xylan content, %	3.6	3.5	2.1	3.2

Evidently, sodium hydroxide behaves differently from potassium hydroxide in the extraction of xylan. For the concentrations employed, the resistant xylan content passed through a maximum at 17.5% NaOH, but passed through a minimum at 24% KOH. For alkali-prepared aspen pulps, 17.5% NaOH was the most unsatisfactory choice for determining resistant xylan. It did, however, give higher alpha-cellulose yields than did more dilute solutions of sodium hydroxide. For the sodium hydroxide concentration used, the 6% solution showed the greatest dissolving power, which supports Meller's views (*22*). It should also be noted that the xylan content of 2.1% obtained with 24% KOH is almost identical with that of 2.0% for the alpha-cellulose obtained directly from chlorite holocellulose using 16% KOH (Table II). Apparently, the differences in the behavior of the xylan in alkali-prepared pulps and that in chlorite holocellulose toward 17.5% NaOH is not exhibited in the case of potassium hydroxide.

The differences observed between the behavior of wood meal and wood chips in the chlorite pulping treatment and the dependence of resistant xylan content on the type and concentration of the alkali used for the extraction also furnish evidence that the phenomenon of resistant xylan in alkali-prepared pulps is related to the physical availability of the xylan to the extracting medium rather than to a chemical combination between xylan and cellulose or to the formation of anhydrohemicelluloses during alkaline treatment.

It was decided, therefore, to investigate the physical means of increasing the availability of the xylan to alkali.

Further Study of Physical Effects

Beating of a Kraft Pulp. Meller (*22*) observed that beating a pulp reduced the resistant pentosan content.

This was tested on the bleached kraft pulp of Table X, 24 grams of which were refined in a Lampén ball mill at 3% consistency for 4 hr. After removal from the mill, the pulp slurry was thoroughly mixed and divided into two equal portions. One portion was filtered, air dried, and Abbé milled. A second portion was filtered and weighed. Knowing the weights of dry pulp and water present, it was possible to prepare a solution of sodium hydroxide of *sufficient* strength that, when added to the moist pulp, it would produce the required volume of 17.5% NaOH. Other air-dried and the undried beaten pulp samples were converted into alpha-cellulose by the standard procedure. The yields were not determined. The results are shown in Table XIII in comparison with the air-dried unbeaten pulp.

Table XIII. Effect of Refining on the Resistant Xylan Content of a Bleached Kraft Pulp

Source of alpha-cellulose	*Resistant xylan content (17.5% NaOH), %*
Unbeaten pulp (air-dry)	9.2
Beaten pulp (air-dry)	5.4
Beaten pulp (moist)	2.2

These results substantiate those of Meller (*22*). Apparently, xylan can be made more available to sodium hydroxide, probably by a disruption of the fiber structure.

Dry Grinding of Aspen Chlorite Pulp. A sample of aspen chlorite pulp was ground by one pass through a small Wiley mill. The 60 to 80-mesh fraction was recovered and converted to alpha-cellulose by the standard procedure. The results obtained before and after grinding are compared in Table XIV.

Table XIV. Effect of Grinding on the Resistant Xylan Content of Aspen Chlorite Pulp

	Original pulp	*Wiley mill ground pulp*
Alpha-cellulose content (based on bleached pulp), %	83.6	79.7
Alpha-cellulose yield (based on original wood), %	51.4	49.0
Resistant xylan content (using 17.5% NaOH), %	8.1	4.5

The results also show that disruption of the fiber structure increases the amount of xylan removed by sodium hydroxide solutions. This serves to explain the difference in behavior on chloriting between wood chips and wood meal; namely, that alpha-celluloses high in resistant xylan could be obtained by the chlorite pulping procedure from the chips and not from the meal.

Extraction of Moist and Air-Dry Bleached Kraft Pulp. The data of Table XIII show that air drying the beaten pulp caused an increase in the resistant xylan content over that obtained on extraction of the undried pulp. A similar effect may take place on drying an unbeaten pulp. A sample of unbleached kraft pulp was bleached for 1 hr. by the standard procedure. By the same procedure used for the beaten pulp, one fourth of the moist bleached pulp was extracted with 17.5% NaOH for 45 min. The remaining pulp was divided into three equal portions and dried under three different conditions. One portion was conditioned for 2 days at 70°F. and 50% R.H., a second portion was conditioned for 2 days at 100°F. and 20% R.H., and the third portion was dried *in vacuo* at 50°C. The conditioned pulps were stored in moisture-tight bottles and finally converted to alpha-cellulose by the standard 17.5% NaOH procedure. The yields were not determined. The results are presented in Table XV.

Air drying increases the resistant xylan content, as does oven drying. No dependence on moisture content was evident in the air-dry range of 4.3 to 7.1% moisture. Thus the transition from wet to air-dried pulp increases the resistance of the xylan to extraction much more than does the transition from air-dried to oven-dried pulp. This is in accord with Whistler's (*5*) statement that "presumably when highly hydrated polysaccharide material is slowly air dried, the gradual removal of water molecules allows neighboring polysaccharide molecules or chain segments to come gradually into contact and thereby establish strong secondary unions which later restrain the separation of the molecules and, hence, the penetration of water or solvent molecules."

Table XV. Effect of Drying on the Resistant Xylan Content of a Bleached Kraft Pulp

Source of alpha-cellulose	*Moisture content, %*	*Resistant xylan content, %*
Undried bleached pulp	..	5.2
Air-dried bleached pulp (70°F., 50% R.H.)	7.1	8.8
Air-dried bleached pulp (100°F., 20% R.H.)	4.3	8.7
Oven-dried bleached pulp (50°C. *in vacuo*)	0.5	9.2

Isolation of a "Sodium Hydroxide Resistant" Xylan

The isolation of this resistant xylan was carried out on a portion of the large-scale alpha-cellulose preparation containing 8.1% resistant xylan by the use of 24% KOH. Fifty grams of the air-dry alpha-cellulose were extracted with 1000 ml. of 24% potassium hydroxide for 45 min. The fibrous residue was filtered and the filtrate poured into 5 liters of ethyl alcohol containing 300 ml. of glacial acetic acid. The resulting precipitate was centrifuged, washed with alcohol and ether, and dried overnight in a vacuum oven at 50°C. The fibrous residue was washed thoroughly and air dried; the yield was 47 grams.

Between 2.8 and 2.9 grams of resistant xylan were recovered, of which 0.2 gram was hydrolyzed with 2 ml. of 72% H_2SO_4 for 1 hr., diluted to 5% H_2SO_4, and refluxed for 3 hrs. This hydrolyzate was then chromatographed without neutralization or concentration (*27*). The results showed that the hydrolyzate contained only xylose. Careful examination of the chromatogram under ultraviolet light revealed no traces of other sugars or sugar acids.

Analysis of this resistant xylan by the standard distillation procedure indicated 90.5% xylan. The product retained 8.9% ash (on ignition). There was strong evidence that this ash was potassium bicarbonate which was present as carbonate as an impurity in the potassium hydroxide. Thus, the resistant xylan (prior to ignition) probably contained 10.1% $KHCO_3$ and 90.5% xylan.

The alpha-cellulose residue from the above extraction contained 2.3% xylan, a considerable reduction from the initial 8.1%. The total material dissolved in the extraction per 100 grams of original alpha-cellulose was 6 grams. The xylan dissolved was also approximately 6 grams. This indicates that, except for its ash content, the material was a pure xylan. Presumably, the low molecular cellulose or glucan is dissolved by the 17.5% NaOH sodium hydroxide and the residual cellulose (anhydroglucose chains) is completely insoluble in 24% KOH.

GENERAL DISCUSSION

Pentosans in hardwood kraft or soda pulps are very resistant to sodium hydroxide extraction. The amount of this resistant xylan seems to be fairly reproducible. A repetition of March's work gave values of 8 to 9% resistant xylan when 17.5% NaOH was used. As early as 1933 Klingstedt (*16*) reported 10.9% resistant xylan in an aspen kraft pulp using 17% NaOH.

This resistant xylan is not materially lowered by strong sodium chlorite bleaching conditions. On the other hand, direct sodium chlorite treatment of wood greatly reduces the resistant xylan content of a subsequently formed alpha-cellulose. It is very difficult to explain this behavior without assuming that alkaline treatment chemically alters the lignin-carbohydrate system so that sodium chlorite reacts differently with xylan after an alkaline treatment than with out one. A possible explanation would be that alkaline splitting of a lignin-xylan bond produces different chemical groups in the xylan molecule than direct chlorite oxidation of such a bond.

A kraft cook on chlorite holocellulose extablished that kraft liquor is relatively mild in its action on xylan. It does not increase the resistance of xylan to alkali after chlorite treatment. However, in the absence of lignin, the attack on cellulose increases.

Chlorite pulps prepared from aspen chips and shavings after alkaline treatment behaved very similarly to the kraft and soda pulps with respect to their resistant xylan content and its response to various bleaching and extraction operations. Direct chlorite delignification resulted in low resistant xylan contents. Thus, alkaline treatment appears to protect the xylan. This effect may be due to a chemical change in the xylan caused by the alkaline treatment. On the other hand, the xylan may actually diffuse more deeply into the cellulose of the secondary wall during the swelling conditions of the alkaline treatment.

When this chlorite pulping procedure was applied to wood meal, the amounts of resistant xylan obtained were far lower than with chips or shavings. When alkaline pulps were refined in a Lampén mill or ground in a Wiley mill, the resistant xylan content also decreased, indicating the importance of retaining the fiber structure. The grinding action cuts the fibers open so that diffusion of alkali into and xylan out of the cell wall can take place through the inner layer of the secondary wall as well as through the outer layer. The refining action in the Lampén mill causes disruption of the cell wall through crushing and fibrillation, thus promoting penetration of the alkali into and diffusion of the dissolved xylan out of the fibers.

The experiments showing the difference in action between sodium and potassium hydroxide support the physical concept of mixed crystallization and secondary valence forces. If the xylan were chemically combined with the cellulose, potassium hydroxide would presumably not be able to remove the xylan more selectively than sodium hydroxide. The isolation of a pure resistant xylan with potassium hydroxide is strong evidence of this. A difference in the penetrating or dissolving powers of the two alkalies is probably responsible for their difference in extraction of xylan.

An increase in secondary valence forces between cellulose and xylan as water molecules are removed, may explain the increase in resistant xylan content caused by air drying [cf. Whistler (*5*)].

CONCLUSIONS

1. There is a marked difference in the amounts of xylan retained in the alpha-cellulose prepared from an aspen kraft pulp and that prepared from an aspen holocellulose. The latter contains far less xylan than the former.

2. The alkaline cooking processes produce aspen pulps containing considerable amounts of xylan which is resistant to extraction by 17.5% NaOH. There is no evidence that kraft or soda cooks produce resistant xylan from otherwise nonresistant xylan; the effect is due to the protective delignification action which takes place and the inability of 17.5% NaOH to dissolve the xylan from the well-preserved fibers.

3. Resistant xylan is not produced from the nonresistant xylan of a chlorite holocellulose on kraft cooking.

4. Grinding to produce wood meal and grinding or refining of a pulp increase the physical availability of the xylan to the extracting alkali.

5. Resistant xylan is not generated from cellulose during the kraft or soda cook.

6. Hot dilute alkali is less effective in removing xylan from a holocellulose than is cold concentrated alkali but the former removes more nonxylan carbohydrate than does the latter.

7. Alkaline pretreatment is necessary to insure the formation of chlorite pulps high in resistant xylan.

8. Drastic chlorite bleaching of a pulp containing large amounts of resistant xylan does not measurably reduce the amount of the latter.

9. The use of shavings or chips for the preparation of chlorite pulps leads to products high in resistant xylan, whereas wood meal, treated similarly, does not yield large amounts of resistant xylan.

10. Potassium hydroxide is far more effective in dissolving xylan from alkali-prepared pulps than is sodium hydroxide. The extractive power of potassium hydroxide is not as greatly influenced by the fiber structure as is that of sodium hydroxide.

11. Air drying of a kraft pulp increases the amount of resistant xylan.

12. The alkali resistance of a portion of the xylan in a kraft pulp is apparently due in part to physical factors such as the fiber structure, secondary valence forces, and high molecular weight. However, the insolubility of this resistant xylan, by reason of its chemical constitution—namely, its apparent lack of uronic acid groups—may also be partly responsible for the dif-

ficulty encountered in extracting it with concentrated alkali.

13. A relatively pure xylan (containing only xylose units plus inorganic impurities) may be obtained by extracting aspen alpha-cellulose (made with 17.5% NaOH) with 24% KOH.

14. The extent of xylan removal from a kraft pulp or a holocellulose depends on the type of alkali used, its concentration, and the physical condition of the fibrous material (e.g., its fineness of division, moisture content, and the like).

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Measurement of Wet Web Strength

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An instrument for the measurement of the tensile strength and stretch of very weak webs or films is described. Particularly for paper wet webs, the tester has the advantage of obviating distortion of the web from plastic flow or clamping pressures. The strain is measured also with good precision without affecting in any way the simultaneous stress measurement. The stress and strain are automatically recorded on an electronic recorder over an area of 100 sq. in. The factors influencing the measurements are described, and precision data for the results obtained with the instrument are shown.

Wet web strength is of importance not only in the obvious relation of the ability of the web to withstand tensile stresses during the manufacture of paper, but also in relation to the general understanding of the structure of the final web and the interfiber relationships in that structure. It is apparent that differences in fiber structure and properties, and minor deviations in the mode of deposition of these fibers in forming the initial web, should exert a considerable influence on the physical properties of the web immediately following its initial formation. Each succeeding phase during the manufacturing operation has a further important bearing on the structure and properties of the finished paper, not only as a result of interfiber relationships brought to bear through water removal, but also as a result of changes following directly from stresses applied during the various stages of water removal.

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The present work deals with the development of an instrument for the measurement of the strength of the web during the manufacture of paper, at such stages where large proportions of water are present and therefore where the web is relatively weak. Although the range of consistency of primary importance is about 20% to 35% solids, i.e., representing the web from the couch to the last press, there is considerable theoretical value in measurements at lower consistencies, and actually with the instrument to be described, reasonably satisfactory measurements have been made on webs containing only 8% solids, representing a rather early stage of web formation quite far back on the wire. The upper limit of solids capable of measurement is governed merely by a minor variation in the means used for load application.

A review of the published literature dealing with the measurement of wet web strength shows a general division into two broad classes of instruments involving (1) the measurement of bursting strength (*1*, *2*, *3*) and (2) the measurement of tensile strength (*4–9*). The interpretation of bursting strength is admittedly complicated, and bears no direct relation to the stresses applied during the manufacture of paper. The measurement of tensile strength has not only the advantage of direct interpretation, but also the very important further advantage of ready adaptability to stress-strain measurements over a wide range prior to rupture. Very little is known concerning stress-strain properties in relation to running properties on the ma-

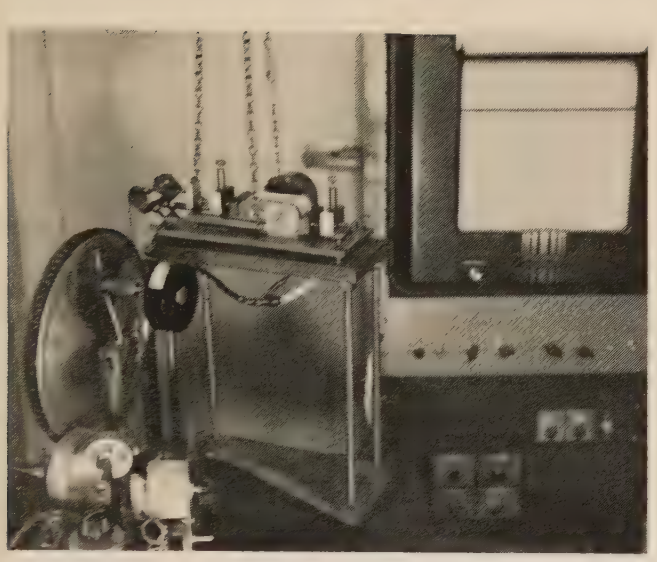

Fig. 1. Wet web autographic tensile tester

chine, but it would appear altogether likely that elongation values and even elasticity coefficients might prove of considerable interest not only in relation to manufacturing operations, but in a broadening of our knowledge of the wet web.

Instruments which measure tensile strength involving a vertical mounting of the test strips (*5, 6, 9*) show several serious defects. Wet webs exhibit a high degree of plastic flow and this distortion is quite appreciable even under the weight of the strip alone. These webs are obviously very readily distorted and it is very difficult to fix the ends of test strips in ordinary clamps without serious distortion. Other instruments which hold a test strip in the horizontal position but involve a long unsupported section of the web under measurement (*10*), show the same deficiency and difficulties.

The instrument developed by Brecht (*4, 11*), and used by other workers (*7, 8*), was designed to overcome these difficulties. The test strip is mounted horizontally and only a very small section under test is unsupported. In this instrument, clamping difficulties are avoided by pressing the test strip onto the movable and fixed heads. This however, involves the risk of a considerable distortion of the test strip in the 30 by 3-mm. unsupported test zone between these clamping plates. Such a distortion resulting from this mounting technique would produce also a zone of higher but undeterminable moisture content in the test area. In view of the very close dependence of strength on moisture content, this would appear to be of critical importance. A different method of load application appeared desirable also. The Brecht instrument has no provision for the measurement of elongation under stress, and the modification described by Langins (*8*) involves a means of strain measurement which does not lend itself to stress-strain measurements prior to rupture.

INSTRUMENT

The presently developed wet web tester involves a number of important innovations over the Brecht instrument in order to obviate these difficulties. In order to eliminate the effects of the heavy clamping pressures near the test zone, the test strip was carried over the curved rear edges of the heads and clamped at right angles to the direction of stress. In view of the difficulty experienced in inserting such weak and plastic webs into regular screw-operated clamps, a fast acting magnetic clamp was devised which could be snapped shut or open. In the earlier stage of development, the movable head was supported on ball bearings, but it was later found that the initial load required to overcome friction was considerably greater than that required to overcome subsequent rolling friction and that furthermore, extended use of the instrument brought about distortions in the tracks which added an irregular resistance to the loading. The movable head was then hung from an overhead support. Chainomatic loading was found to be very satisfactory as a means of load application, providing a method of rapid change of load ranges while retaining the same precision and rate of loading. This was achieved by the use of a d.c. motor, the speed of which could be controlled by a rheostat. In an intermediate model, a mechanical drum and pen assembly was provided for the recording of stress and strain, the drum rotating with increased load and the pen moving with the motion of the movable head to record strain. This system of recording showed difficulties in linear recording of strain and was later completely replaced by an electrical system as described below. The general scheme of mounting of the strips proved very satisfactory in use, and the zone under stress remained undistorted and supported over its entire length until loading commenced.

The present design of the instrument is shown in Fig. 1, and schematically in Fig. 2. The stainless steel movable head A is 2 in. wide, $1^1/_2$ in. long, and 1 in.

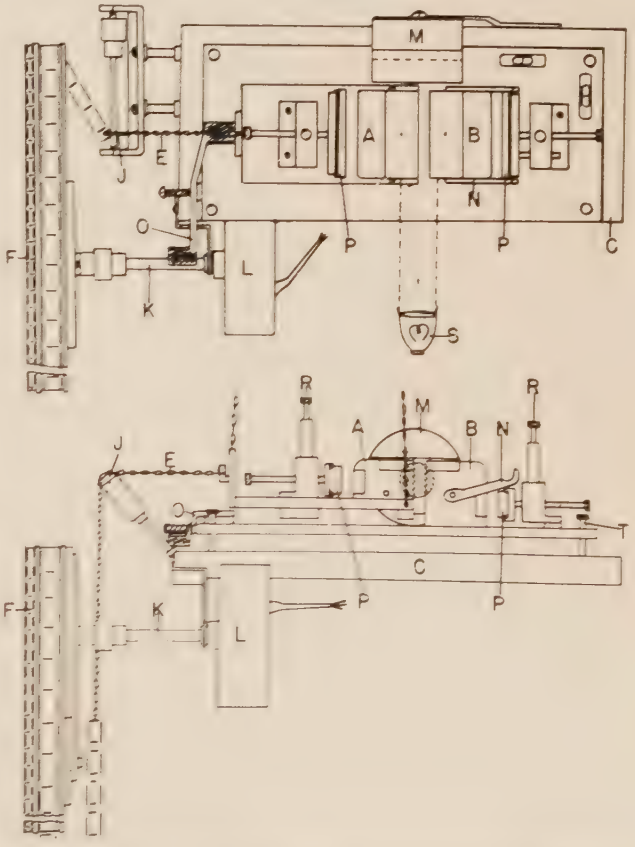

Fig. 2. Schematic diagram of wet web autographic tensile tester

high. It is suspended from three 4-ft. chains, the apex of which is displaced sufficiently to permit the head to hang without load when a gap of 1/4 in. exists between the two heads. This assures a minimum load to move the head at the point of rupture of the web. The fixed head B of the same dimensions as A is mounted on a table fitted with leveling screws, which in turn rests on an iron base, C, sufficiently heavy to resist motion when the web ruptures. This heavy base is fastened to the chainomatic loading unit which consists of a balancing arm to which the chain E is attached. The chain is wound on a drum F, driven by the d.c. motor controlled by a rheostat. The chain is attached to the movable head over a pulley J.

For the recording of the load and elongation, each of these factors is translated into an electrical impulse which in turn is fed to an X-Y recorder. Load is recorded directly from the rheostat L rotating with the chain load. The strain-recording mechanism is not clearly represented in the photograph and will therefore be described in some detail. Since the force required to actuate a rheostat to register elongation would require a load on the movable head approaching the breaking load of the weakest wet webs, an optical method was developed. A strong collimated beam of light is directed onto the sides of the movable and fixed heads at their junction. A photoelectric barrier layer cell M is mounted directly behind the heads and masked so as to be affected only by the light transmitted through the widening gap between the heads as the web elongates under stress. The output from the cell is sufficient to operate the recorder. The strain signal can be magnified readily electrically, so that the entire X-axis scale on the recorder can be used. The stress signal can also be magnified electrically so that the load of the heaviest and also of the lightest chain can be made to cover a distance equal to any multiple of the corresponding strain. This versatility of the photoelectric system coupled with the recorder renders the stress-strain diagrams easily interpretable. The motion of the pen is linear with increasing gap width. This was checked by using a traveling microscope to measure the gap width and a comparison of the values recorded on the X-axis. The load applied is also linear with the movement of the chart in the Y-axis direction. With the X range set by feeler gages of accurately known thickness, and the Y range set by values on the dial K, the load in grams and the strain in per cent elongation can be read directly from the automatic graph.

SHEETMAKING AND TESTING PROCEDURE

Early trials showed clearly that the details of procedure used in preparation of the wet web test sheets must be rigidly adhered to in order to obtain reproducible results. Much of the work reported in the literature cannot be correlated as a result of lack of details of this sheet preparation. It was further concluded that wet web strength values determined for only one moisture content were inadequate for study in view of the varying freenesses of the pulps studied. In all cases therefore, measurements were made over a range of moisture contents in order that interpolation to any fixed moisture content could be obtained. In order to incorporate the effect of basis weight changes, load figures were converted from grams per inch width to breaking length, considering the moisture-free weight of pulp in the sheet. This weight was chosen rather than the total wet weight in view of the greater degree of accuracy involved in its measurement.

A typical example of procedure is as follows. A sample of slush pulp is mixed in the British disintegrator until well dispersed, or a larger sample of lapped pulp is slushed in the Valley beater for 5 min. without load at 2.5% consistency, and a sample removed. The slushed and dispersed pulp is diluted so that 2 grams (moisture-free) are contained in 500 ml. of stock. Freeness is measured and a 2-gram (moisture-free) handsheet is prepared in the British sheet machine using TAPPI Standard T 205 m-50. The wet web is couched from the wire with one new blotter and backing plate using two complete rolls of the standard brass couching roller, commencing at the center of the sheet. The sheet is immediately covered with a damp blotter and carried to the constant humidity room where it is trimmed as rapidly as possible to 5 by 4 in. Eight 1/2-in. or four 1-in. strips or combinations of these are cut in the longer dimension while the web is still supported by the backing blotter. The strips are then carefully peeled from the blotter and laid on a wire mesh to dry at either 73°F. and 50% R.H., or under a single 250-watt infrared lamp located 24 in. above the strip and totally enclosed on three sides by a metal box. At definite intervals of time, e.g., 0, 3, 7, 10, 12, 15, 20, 30-min. strips are transferred to the table of the tester, and after centering the strip, the ends are bent down between the clamps and the magnets released. The main clamp N holding the movable head to the fixed head is opened and the second steadying clamp O is also removed at the same time as the chain loading is commenced. The rate of loading is approximately 3.6 grams per sec. The stress and strain are automatically recorded on the X-Y recorder which had previously been calibrated to grams load per chart unit, and per cent elongation per chart unit. Immediately after rupture, the strips are removed from the quick-opening magnetic clamps and transferred to glass-stoppered weighing bottles. These are weighed after measurement of the series and left in the oven on blotters for a minimum of 4 hr., cooled in a desiccator, and reweighed in the weighing bottles. The per cent solids at the time of testing and the moisture-free basis weight are calculated. The stress at rupture expressed as breaking length is plotted against the per cent solids of the strips. The per cent elongation at rupture is also obtained from the X-values and tabled.

In more recent work, it has been found advisable to make duplicate sheets and cut both to yield sixteen 1/2-in. or eight 1-in. strips. These are tested in random order after drying for 0, 3, 6, 9, 12, 15, 18, 21, 24, 26, 28, 30, 32, and 34 min. with two strips held in reserve as replacements in case of accident or for totally air-dried values after 16 hr. under standard temperature and relative humidity.

FACTORS INFLUENCING WET WEB VALUES

Strip Width

The tester can accommodate a strip of width up to 2 in. A linear relationship was found for widths from

1/2 to 1 1/2 in. Widths of less than 1/2 in. showed a slight decrease in load per unit width, presumably resulting from edge effects. Increasing clamping and aligning difficulties were noted also below 1/2 in. width. Widths were standardized at either 1/2 or 1 in.

Basis Weight

At constant moisture content, the relationship between tensile in grams and basis weight was found to be linear for a basis weight range of 45 to 90 lb. (24 × 36—500). The load to rupture fell off sharply below this range. A standard basis weight of 61.5 lb. (24 × 36—500), i.e., 2-gram moisture-free handsheet, was adopted. Plots of wet web tensile at rupture for increasing per cent solids showed almost linear curves of increasing slope for increasing basis weight. This same relationship was observed by Langins (*8*) and Schröter (*7*). It was found that the conversion of stress values to breaking length resulted in a single breaking length versus per cent solids curve, again similar to the relationship noted by Schröter.

Rate of Loading

No difference in tensile values was noted over a range of rate of loading from 3 to 100 grams per sec.

Solids Content

Under the atmospheric conditions during measurement, i.e., 73°F. and 50% R.H., the wet web solids content was found to change about 3.5% in 300 sec., during which interval some ten tensile measurements could be made. This change in moisture content can bring about enormous changes in tensile strength, e.g., as high as 400% in the moisture range of greatest interest. Furthermore, moisture determinations on 24 strips from six similarly made handsheets showed a spread of 3% in moisture content which again would occasion very serious errors. It therefore became necessary to measure the moisture content of each test strip. Since the strip is measured for strength only 15 to 30 sec. prior to moisture measurement, the moisture change during that interval is of the order of less than 0.15%.

Deviations in Sheetmaking Procedure

As noted above, moisture content is a critical factor and any change in sheetmaking procedure alters this factor. Pressing a wet web to a desired moisture content yields a sheet with quite different wet web strength to one obtained by air drying to the same moisture content. This is a major reason for the discrepancies noted in wet web tensile values in the literature. Some compacting was considered desirable to raise the solids content to 12 to 15%, and to afford a uniform couching procedure, and a compromise was effected in two rolls of the couch roller. This simulates reasonably well the treatment of the sheet on the paper machine by the suction boxes and couch roll as contrasted with the more severe pressing procedure used in wet web burst testing (*1, 3*) or in some wet web tensile testing (*5, 6, 9*). It is however more than that given test sheets prepared by Brecht (*12*) or Langins (*8*) who used vacuum water removal on the wire followed by couching without further water removal.

PRECISION OF PRESENT WET WEB TESTER

Measurement of Stress

The standard deviation of the load required to rupture 24 test strips of sulphite pulp with high wet web strength, and 17 test strips of groundwood with low wet web strength were 10.5 and 5.8 grams per 1/2-in. width, respectively. This shows coefficients of deviation of ±4.7 and ±6.0%, respectively.

These coefficients are for values uncorrected for basis weight or moisture. A similar set of 16 tests on bleached sulphite corrected for these two factors gave standard deviations of ±2.7 and ±1.6 meters, or coefficients of ±5.2 and ±3.9% for 1/2 and 1-in. wide strips, respectively. These values are of the same order of variance as those for other tests carried out on paper and agree well with those given by other investigators carrying out similar measurements. Thus, Langins (*8*) obtained ±4.1 and ±2.4% for uncorrected and corrected coefficients. De Montigny (*1*) noted a coefficient of ±4.3% on wet burst tests.

It is apparent that a close control must be maintained on the variables noted. It is emphasized that moisture content must be suitably corrected for, or obtained by interpolation from a range of data. From the above, it would appear that the expected error in single tensile measurements is about 2.7 meters and for three consecutive measurements about 1.5 meters of breaking length. Heretofore mainly only single measurements at any fixed moisture content have been made.

It is interesting to note in measurements made with glass fibers, that the coefficients of deviation are considerably greater than with wood pulp. An average coefficient for corrected measurements on webs comprising glass fibers of 0.75 mu diam. at 13% solids, is ±8.4% and at 20% solids is ±16.8%. This large deviation is probably connected with the more rapid evaporation of water from the system and the greater resilience of the glass fibers, together with the very steep gradients of strength changes with increasing solids content.

Measurement of Strain

In calibrating this motion for translation into per cent elongation, it was not only necessary to use a traveling microscope for calibration of the actual gap between the heads, but it was also necessary to establish the length of the test strip undergoing strain. It had been assumed in design that only the horizontal segment of the strips, i.e., from tangent point to tangent point of the two heads, would elongate.

In order to determine the actual length undergoing elongation, webs of sulphite and groundwood were prepared and after positioning on the tester, parallel lines across the strips were drawn 1/2 and 1 in. on each side of the center boundary and at the two tangent points. These lines were photographed together with a millimeter scale at intervals during the stressing to rupture. The distance between these lines could thus be accurately measured at known gap openings marked on the recorder chart at the moment of taking each photograph. The elongation had already been calibrated by a cathetometer as previously noted. The length to give coincidence between the per cent elongation from the separation of the lines on the photograph and the separation of the heads recorded on the chart was 2 in.

with a standard deviation of ±0.3 in. This is the total horizontal distance between the tangent points of the curves of the two heads. Thus it is apparent that while most of the stretch occurs over the zone which is rupturing, the entire wet strip in the horizontal plane stretches to some degree and the strain recorded is expressed on this total length.

Mechanically, the strain can be measured to within ±0.06%, but the coefficient of deviation for actual measurements on $^1/_2$-in. strips is ±6.2%, showing that the variation lies in the pulp and web and not in the precision of the test instrument. For glass fibers, the coefficient is again larger than for wood fibers, averaging about ±10.0%.

Applications of the instrument described above in various researches will be described in subsequent publications.

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Studies in the Fundamentals of Wet Web Strength

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Using a wet web tester previously described, measurements of wet web strength have been made on various fibrous webs at solids contents down to 8%. The importance of surface tension effects and their limitations are illustrated by experimental evidence. By means of glass fiber webs, with and without bonding agents, a separation is achieved between the surface tension and interfiber bonding effects. It is concluded that the general mechanism underlying the development of strength in paper webs is as follows. Up to about 20 to 25% solids, the fibers are held together with increasing strength essentially by surface tension forces. These forces then show a rapid decline and in this region, partly as a result of the greater density achieved, interfiber bonding becomes the major factor. The strength then increases continuously to dryness. The interrelationship between these two mechanisms is illustrated. Frictional resistance to tensile failure of the web is superimposed on the other forces at all stages of strength development.

The applications of paper are many and varied and involve a long list of individual properties. Some of these properties have been intensively studied while others appear to have received scant attention, in many cases presumably as a result of the complexity of the problems involved. Some of these properties relate to functional aspects of the uses of paper and others govern the aesthetic qualities. There is a very broad and complicated interrelationship among these numerous quality factors, and, in general, an advancement of the knowledge of one of these qualities results in increased knowledge of others. From a broader point of view, we are dealing with the structure of a web. The properties of this web will depend in turn on the properties of the individual fibers in the web, on their positioning in the web, and on the degree of attachment among these components.

The development of strength in the web as water is removed is of considerable interest in contributing to the knowledge of the structure of the web. In Fig. 1, general curves are shown noting the relationship of tensile strength to per cent solids in the web. Such a relationship is obtained not only directly on drying webs, but is reproduced also by the stresses developed during drying if the web is not allowed to shrink (*1*). These investigations have with few exceptions been confined heretofore to solids contents upwards of 35%, representing essentially the drier section of the paper machine. In a previous publication (*2*), an instrument suitable for measurements at solids contents as low as 15%, and on which indeed measurements have been made with a fair degree of precision with solids contents as low as 8%, representing a stage on the paper machine well back on the wire was described. This paper presents results therefore on the very early portion of the curve of the development of strength with increasing drying, using the wet web tensile tester previously described. A clear distinction must be emphasized between this investigation on wet webs and what has been termed secondary wet strength, i.e., the strength of finished paper subsequently remoistened. The experimental procedure used in the preparation of the webs and in the measurements has been given in detail in the preceding paper.

Figure 2 shows the course of the tensile strength with increased drying for typical sulphite and groundwood pulps. These represent, on a suitably enlarged scale, the early portion of the general curve shown in Fig. 1. In all cases, it is noted that the increase in strength is not continuous. A marked inflection is noted in the 20 to 30% solids region showing a very pronounced break in the general course of strength development. It appeared of particular interest to investigate further the reason for this discontinuity. In general, it may be accepted that the web attains increasing strength during drying as a result of the development of interfiber bonds. There is no doubt of the existence of these bonds and of their importance in the properties of

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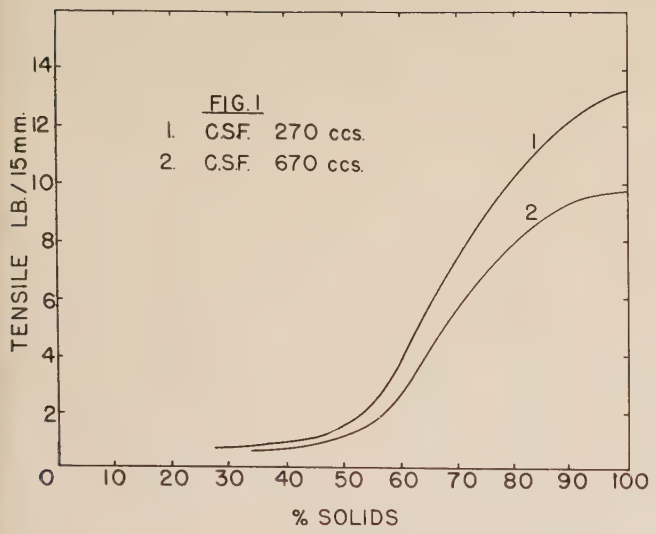

Fig. 1. Development of strength of bleached sulphite webs with increasing dryness

finished paper. If bond formation is initiated during the very early stages of water removal, e.g., 12% solids, then some explanation would have to be found for a marked interruption in such bond formation in the region represented by the deflection. It would appear that such a discontinuity in bond formation could be brought about only by a relatively sudden alteration in the positioning or physical proximity of the fibers relative to one another and such a concept appears to be entirely untenable in a system of this kind. The alternative explanation must be based on a concept of two distinct mechanisms governing the increase in strength with drying before and after the region of discontinuity.

If interfiber bonding is ruled out as the only or at least the important basis for increased strength prior to the inflection region, it appears altogether likely that this early strength development is brought about by a change in the medium surrounding the fiber components of the web. At very low concentrations, the web is completely immersed in the water medium. Rough calculation based on the caliper of the wet web and the densities of fiber and water shows that voids begin to appear in the web at about 12% solids and increase steadily with water removal. There is thus introduced an increasing area of air-water interface into the web with accompanying increased surface energy. It appeared of particular interest to adduce evidence of the importance of this factor in wet web strength and to investigate systems in which interfiber bonding could be ruled out or brought into play as desired.

REDUCTION OF INTERFIBER BONDING OF PULP

The influence of a drastic reduction in interfiber bonding on the course of early strength development was investigated. This reduction was effected in two ways; (1) wet webs in which the fibers were coated with a liquid immiscible with water, and (2) wet webs made from pulps containing various proportions of water and laid down in a nonpolar liquid.

Bleached sulphite was oven-dried for 24 hr. at 155°C., then disintegrated and made into handsheets. Another portion of this intensively dried pulp was admixed with 2% by weight of mineral oil, then disintegrated and made into handsheets. A third set of handsheets was prepared after adding 100% by weight of the mineral oil to the dried pulp and disintegrating. The results are shown in Fig. 3. Curve 1 shows the tensile development for undried sulphite. Curve 2 is for untreated dried pulp and it is noted that the strength development is greatly decreased and that no inflection is obtained. This pulp had a dry breaking length of 36 meters, representing only 12% of the ultimate dry breaking length of the originally undried pulp. Curve 3 shows the results for the dried pulp containing 2% mineral oil. It is noted that the strength development follows the course of the untreated dried pulp up to about 25% solids, following which there is shown a distinct maximum and then a drastic reduction in strength as the solids content of the web increases. The tensile strength is about 5.5 meters at 70% solids, as compared with 13 meters at 30% solids. Curve 4 shows the results for webs containing 100% mineral oil based on dry fiber. Despite the extremely weak sheet having a tensile strength of only 1.7 meters breaking length when dry, there is a distinct course of early strength development to that point.

It is well known that a paper web made in a nonaqueous medium possesses only negligible strength and that the absence of bonding under these conditions is consistent with commonly accepted theories of interfiber bonding. A series of handsheets were prepared from sulphite pulps containing varying quantities of moisture ranging from moisture-free to 100% moisture based on dry fiber, all in a medium of anhydrous xylene. The resultant tensile strength development for these webs with progressive drying is shown in Fig. 4. Curve 1 shows for comparison again the strength development for the sulphite pulp in water. Curve 2 shows the results for handsheets made from pulp comprising 50% dry fiber and 50% water in anhydrous xylene. It is noted that the tensile strength increases to a

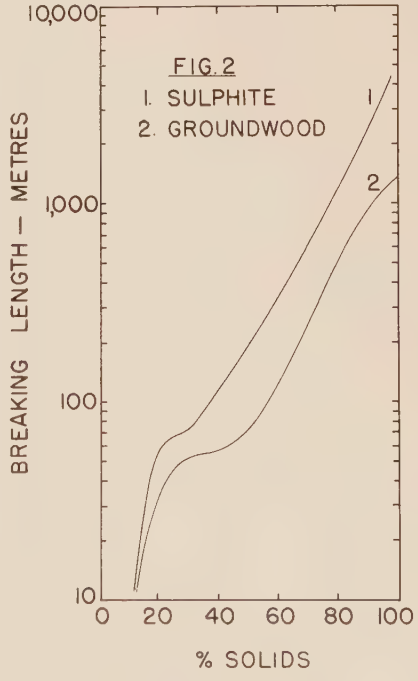

Fig. 2. Development of strength in sulphite and groundwood webs with increasing dryness, showing detail in the wet web region

maximum and then decreases to a value in the dry sheet considerably less than the strength of the same web containing only 15% solids. Curve 3 shows similar results for an air-dry pulp (5% moisture) in anhydrous xylene. The maximum strength is developed in the same region as the inflection point in the aqueous system. Curve 4 shows similar results for a moisture-free pulp in xylene and here it is seen that the maximum is displaced toward a higher solids content as in the case of the treated sheets shown in Fig. 3. These pulps dispersed in xylene to a degree of flocculation similar to that in water and a direct comparison may be made in the aqueous and nonaqueous systems insofar as degree of dispersion of the fibers is concerned.

NONBONDING MODEL WEBS

In order to obviate entirely the possibility of interfiber bonding throughout the moisture range of the wet webs, consideration was given to the use of various natural and synthetic fibers for the manufacture of paper webs under conditions where a complete absence of interfiber bonding in the ordinary sense of the term can be safely assumed. Although other fibers have been briefly investigated, glass was chosen for the major portion of the work for several reasons. Glass fibers are available over a wide range of diameters and therefore afford an opportunity of investigating the effect of fiber diameter and specific surface. Glass fibers show no bonding in a neutral aqueous medium and yield dry webs which possess a very low strength resulting only from the frictional resistance within the web. Furthermore, glass fibers are readily bonded by agents soluble or dispersible in water, if desired. In the main, diameters ranging from 0.25 to 3.8 mu were used. The fibers were prepared by chopping the purchased fibers in a Waring blendor under standard conditions.

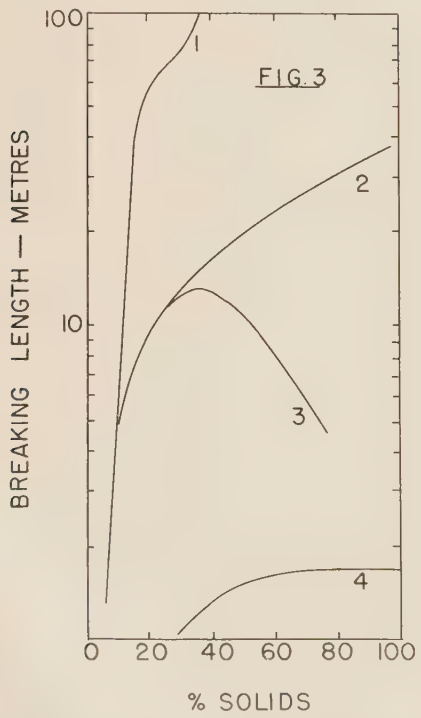

Fig. 3. Effect of decreased bonding on strength development by hydrophobic treatment of sulphite pulp

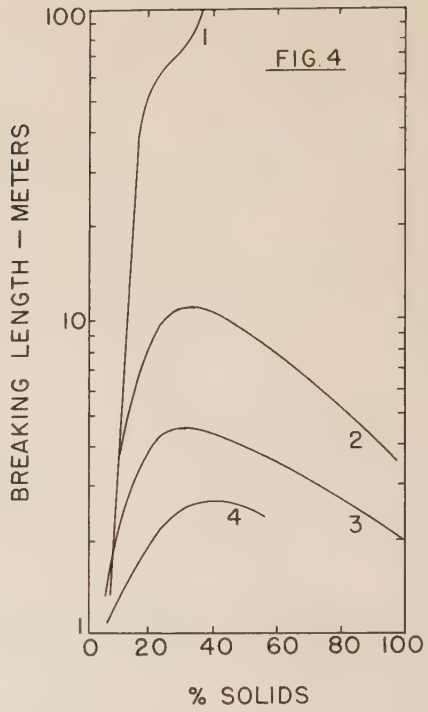

Fig. 4. Effect of decreased bonding on strength development by the use of a nonpolar medium

Figure 5 shows the tensile strength of webs composed of fibers of different diameters. In all cases there is shown a steep rise to a maximum strength at about 20 to 25% solids content, followed by a sharp decrease to low values. The strength of the dry web consisting of 3.8-mu fibers is so low as to be barely measurable, and yet the breaking length of this web at 20% solids content is 75 meters. The maximum strength attainable increases continuously with decrease in diameter of the fibers involved, but the position of the maximum with respect to solids content remains unchanged within experimental error.

It is noted therefore that wet webs consisting of fibers incapable of bonding among one another show a very large increase in strength with progressive increase in solids content to a relatively sharp maximum. Following this maximum, the mechanism responsible for the increase shows a rapid decline. The low strength of these webs when dried must be ascribed to frictional resistance to the pulling out of the web, and this resistance decreases to a negligible value even with fibers as small as 3.8 mu diameter.

Glass fibers can be bonded by means of a variety of bonding agents, or treatments and it was of particular interest to measure the tensile strength of a glass fiber system with increasing solids in the presence of such bonding agents. Figure 6 shows the results obtained on webs consisting of glass fibers of 2.5 mu diameter. Curve 1 shows again for reference the basic relationship obtained for sulphite pulp. Curve 2 shows the results for the glass fiber web without bonding agent addition. The close coincidence of tensile strength between the maximum in the glass fiber webs and the inflection region of the sulphite web is purely fortuitous and shows a relationship to diameter and stiffness of the fibers which will be discussed below. The coincidence with respect to solids content appears of considerable

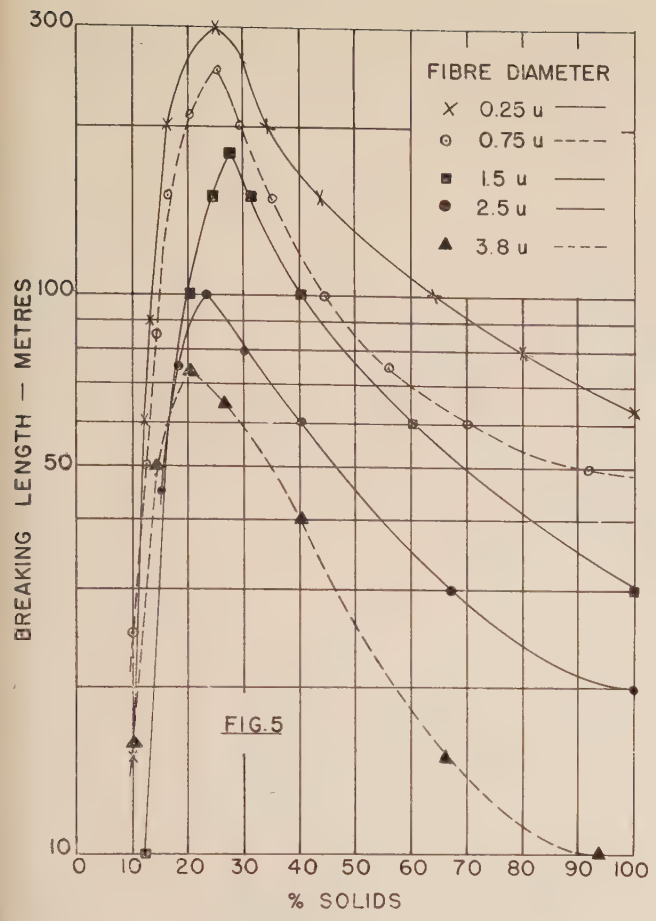

Fig. 5. Strength development in glass fiber webs

theoretical interest and will be dealt with at some length in a later section.

Curve 3 of Fig. 6 shows the effect of hydrofluoric acid and curve 5 represents results following the addition of gelatin to the wet web. In each case the general course of the relationship is similar to that obtained with sulphite pulp which contains a natural adhesive in the hemicellulose fraction. The strength rises steeply, goes through an inflection point, and then continues to rise steeply with further drying to an ultimate dry strength comparable with that of sulphite pulp. Curve 4, showing results obtained using sodium silicate as an adhesive, is particularly noteworthy. Here a steep rise is shown very close to that of the glass fiber web alone, followed by a maximum and initial decline very close to the untreated web. Following this, however, the decline in strength shows a second inflection followed finally by a strength increase comparable to that obtained with gelatin. It would appear with hydrofluoric acid and gelatin that bonding commenced at a much lower solids content than with sodium silicate. It is noted, however, that with earlier bonding, the maximum strength attainable at the inflection point is decreased. Thus the order of decreasing strength in the wet web was obtained with sodium silicate, hydrofluoric acid, and gelatin. The highest wet web strength thus appears to be obtained where interfiber bonding is not yet an important factor. Sodium silicate is not effective as an adhesive until a solids content of about 45 to 50% is reached under the conditions used.

It seems logical to conclude on the basis of this evidence that a fibrous web in the absence of interfiber bonding shows a rapid increase in tensile strength which then decreases sharply with increasing solids. In the presence of a bonding agent, however, it is concluded that the inflection region is a merging of the decrease of the initial reinforcing mechanism and the development of interfiber bonding which continues to increase through to the dry sheet. Curve 4, Fig. 6, is particularly interesting in showing two inflections which are interpreted on this basis as a separation of the decline of the first and development of the second of the two successive reinforcing mechanisms.

SURFACE TENSION

The likelihood of surface tension as the mechanism for the early development of wet web strength prior to the onset of interfiber bonding has already been mentioned above. This topic was further investigated in two main directions: (1) the effect of alteration in surface tension in bonding and nonbonding systems, and (2) the direct measurement of strength development in terms of the attractive forces involved as represented by density.

Figure 7 represents the wet web strength of a glass web consisting of fibers 0.25 mu in diameter in water with reduced surface tension, over the drying range. Curve 1 shows the results in water with no reduction in surface tension. The maximum in breaking length

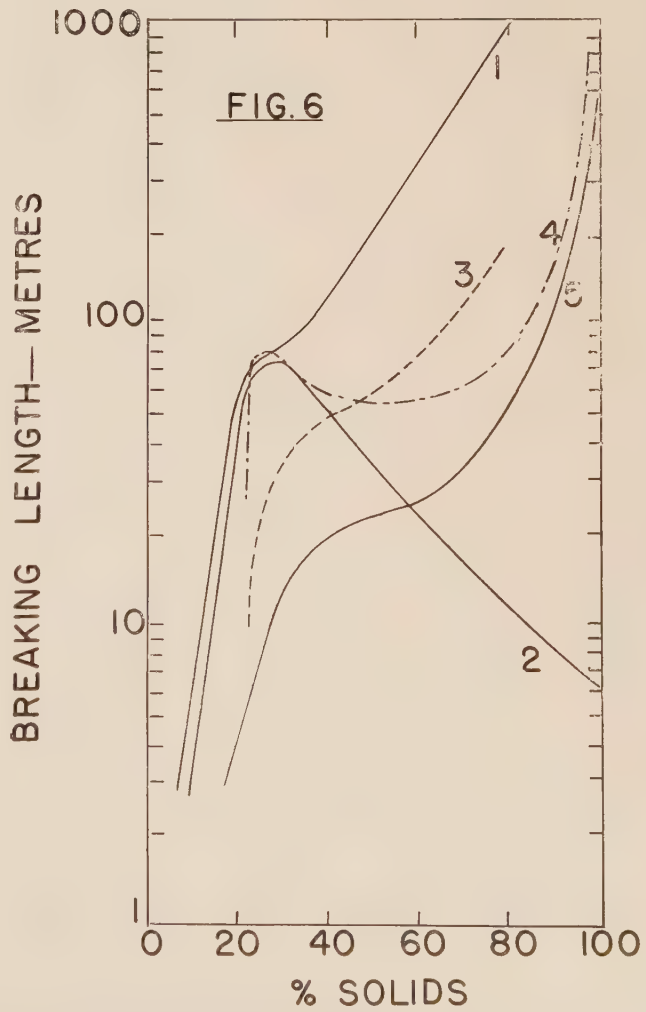

Fig. 6. Effect of bonding agents on strength development of glass fiber webs

is about 300 meters, and is obtained at about 25% solids. Curve 2 shows the results where the surface tension was reduced to 39 dynes by the addition of 0.01% of an anionic surface-active agent to the water prior to deposition. The maximum breaking length is now reduced from 300 to 140 meters, with no displacement of the maximum with respect to per cent solids. Curve 3 shows results for a reduction in surface tension to 33 dynes by the use of 0.1% of the same surfactant, and here the strength is further reduced to about 95 meters with some possible horizontal displacement of the maximum toward higher solids.

Figure 8 shows similar results using spruce groundwood. Curve 1 is typical of groundwood in water showing an inflection point at about 20 to 25% followed by a slower rise than is obtained for sulphite. Curve 2 shows the effect of a lowering in surface tension to 33 dynes by the addition of 0.1% of the same surfactant. The strength is greatly lowered at all stages of solids content. The breaking length at the inflection point is reduced from about 55 to about 20 meters.

The important effect of surface tension on strength development is thus clearly shown. Some attempts were made also at measurements in systems where a large increase in the surface tension of water can be attained, e.g., in a concentrated solution of potassium carbonate, but the direct chemical effects of the surfactant on the fibers rendered any conclusions difficult of interpretation.

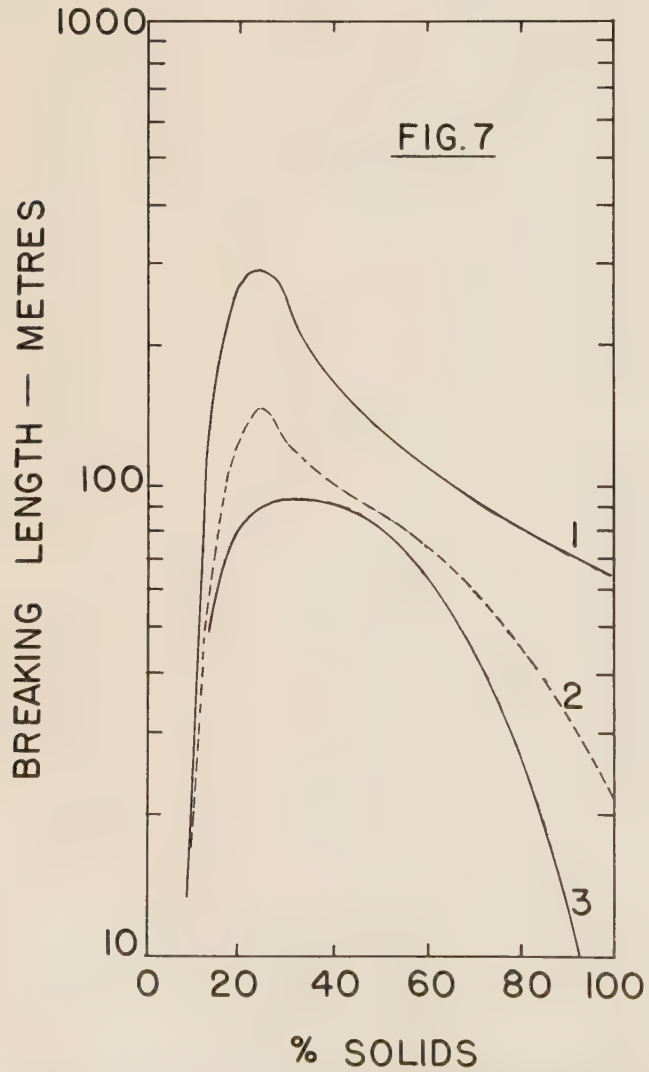

Fig. 7. Effect of reduced surface tension on strength development of glass fiber webs

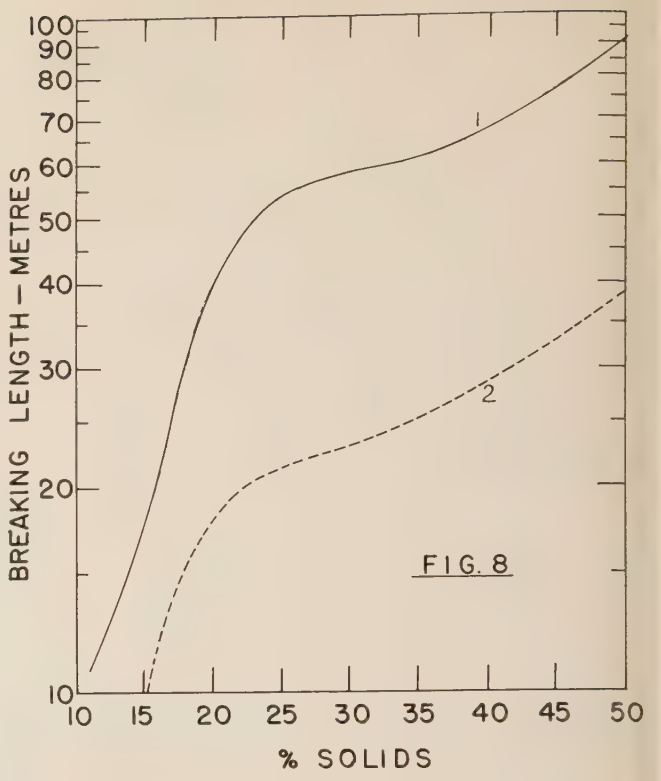

Fig. 8. Effect of reduced surface tension on strength development of groundwood webs

These surface tension forces must actually hold fibers together if they are largely responsible for strength in the very wet webs. Any change in surface energy produced by the introduction of a greater area of interface during the early stages of water removal should therefore be reflected by a corresponding increase in the force holding or pulling the fibers together. It was noted during the course of this work that the change in width on water removal in the range of dryness involved was very small and, it was considered likely therefore that this force should be reflected in appreciable changes in caliper or thickness of the web.

Thickness measurements for this work were carried out using the magnetic caliper gage designed by J. A. Hart and D. J. Wells of our laboratory and already described elsewhere (*3*). This instrument affords a very high degree of precision, but special care was exercised in this instance with respect to loading of the caliper gage. In view of the extreme ease with which very wet webs are deformed, in each case a series of measurements was made with increasing loads. In general, five loadings were applied ranging from 0.8 to 1.8 p.s.i. In view of the small load increments and precision of the readings, extrapolation to the caliper at zero load could be made with a sufficient order of accuracy.

Figure 9 shows the results for glass webs consisting of fibers 2.5 mu in diameter. The thickness of the web decreases steeply with increased water removal until a minimum is reached at about 22% solids. There is then a sharp reversal and the thickness increases with increasing degree of dryness. It is noted particularly that the minimum in thickness of the sheet is obtained

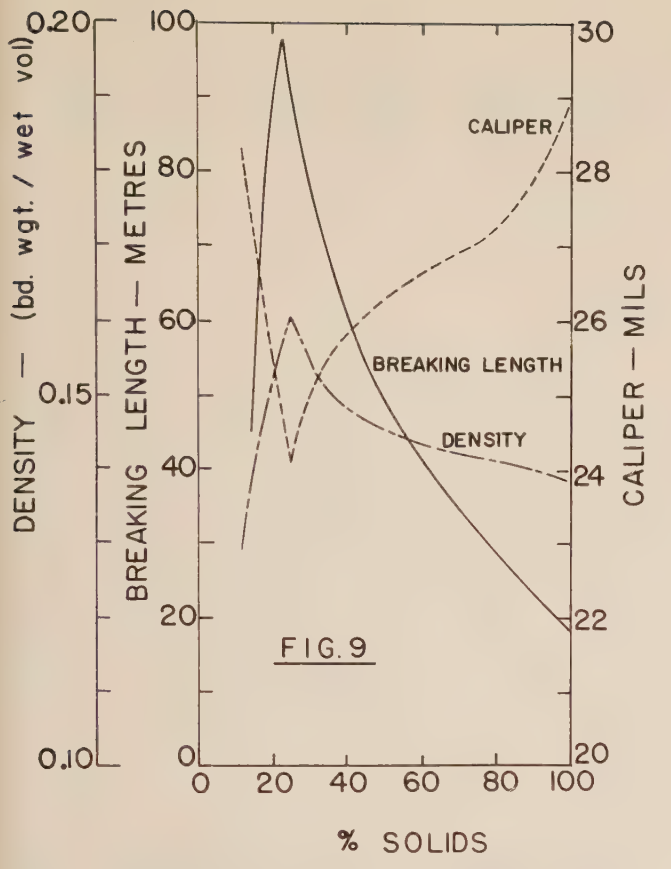

Fig. 9. Relationship of strength to caliper and density with increasing dryness of glass fiber webs

at the same solids content as the maximum in strength. The density curve shown is calculated as the ratio of dry weight of fiber to volume of the wet web.

Figure 10 shows similar relationships for a spruce groundwood pulp. Here again the course of the thickness of the wet web with increasing solids content is essentially the inverse of the strength. The thickness decreases to a region of inflection coinciding with that of the strength curve and then continues to decrease as the strength increases.

The experimental results summarized in Figs. 9 and 10 appear to support strongly the hypothesis of two successive mechanisms for strength development in the wet web. In the glass fiber system, as air-water surface area is increased, the fibers are pulled together more strongly with consequent decreased thickness of the web. Increasing strength is developed. When a definite solids content is reached for any one system, some form of rupture in the medium occurs, following which the force holding the fibers together decreases and at the same time, the tensile strength of the web decreases. In the pulp system, the first portion of the strength development is similar. The failure of the surface tension forces is however accompanied by the appearance of marked interfiber bonding and the double inflection in the strength is well reproduced by a similar double inflection in thickness of the web.

DISCUSSION

The wet web consists of layers of fibers, interwoven not only in horizontal planes but also to an important degree from one plane to another. The degree of preferred orientation and anisotropy generally is of negligible concern in the present work dealing with handsheets. The possibility of fiber-breaking in tensile failure of wet webs is remote, and it may be assumed that breakage results from a pulling out and separation of fibers leading to zones of weakness and eventual failure. In an analysis of the forces available to provide strength in these wet webs, three sources of resistance to loads in tension appear likely to be of importance: (1) frictional resistance to pulling out and separation of fibers, (2) interfiber bonding, and (3) surface tension forces in the water medium.

Frictional resistance undoubtedly plays a part in the strength of all fibrous webs at any degree of dryness. Dry glass fiber webs probably owe their low but very appreciable strength entirely to this strength factor. The magnitude of this frictional resistance to deformation will obviously depend on the complexity or degree of interweaving of the fibers and also on the modulus of the fibers in flexure. It is apparent that the amount of interweaving will increase with decrease of diameter of fiber and therefore for any given basis weight, fine glass fibers provide greater strength than coarser glass fibers. On the other hand, pulp fibers with a relatively very low modulus and a high degree of plasticity when wet, should show much greater frictional resistance than glass fibers for the same surface area involved. In general, it may be assumed that frictional resistance is always operative, superimposed on other mechanisms which may be effective.

Beginning at a very low solids content, on further water removal, the fibers are pulled together in the thickness dimension of the web with a remarkable increase in density and a correspondingly sharp increase in tensile strength. Since it has been shown that this

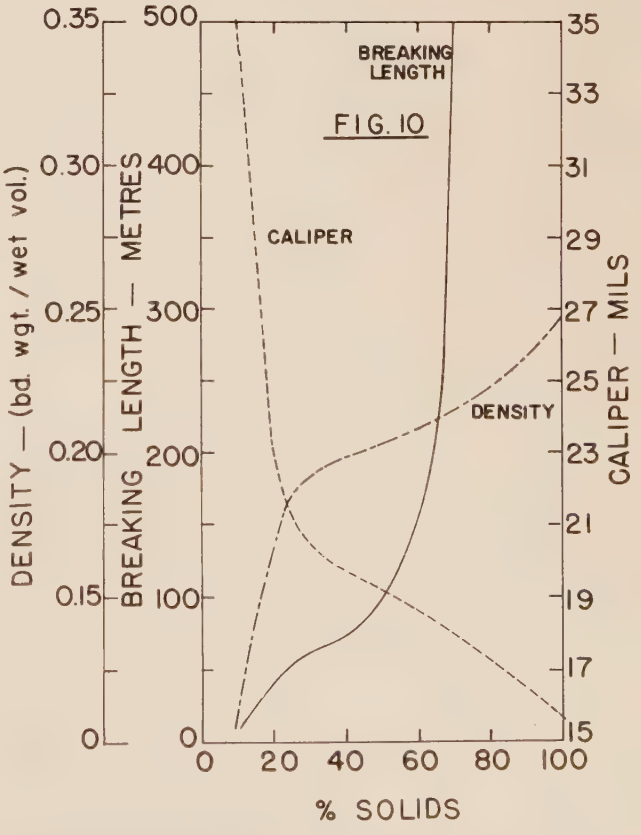

Fig. 10. Relationship of strength to caliper and density with increasing dryness of groundwood webs

effect obtains in nonbonding systems, the explanation of increasing surface energy in this portion of the wet web region appears tenable and is further supported by the effect of alteration in surface tension. As water removal proceeds, voids occur in the web with consequent increased water-air interfaces in the web. These interfaces are pictured as continuous but irregular in contour throughout the web. Fiber-water wetting tensions and fiber-water-air interfaces may also be involved. Eventually a point is reached where these interfaces are broken up into discontinuous patches of water, when sufficient water has been removed. This occurs in the region of 20 to 25% solids and the discontinuity is remarkably sharp. With still further water removal, larger regions of fibers lack this reinforcement and the tensile strength attributable to this decreases to a low value.

Where an adhesive is present, in the form of a natural adhesive as in wood pulp or an extraneous adhesive added to glass fiber, the initial rise due to surface tension forces remains essentially the same. For an adhesive to be operative, the fibers must be brought into close juxtaposition and this is accomplished by surface tension through decreased thickness. Bonding becomes marked soon after the maximum due to surface tension is reached and subsequently the strength increases through to the dry sheet. The inflections are the consequence of a combination of decreasing surface tension strength and increasing bonding strength.

It is not implied in this analysis that interfiber bonding is entirely absent in the initial strength rise. It is rather quite likely in a pulp system that interfiber bonding has a very small and weak beginning quite early in the system, but becomes marked only after the inflection point. Similarly, a decreasing residue of surface tension force remains subsequent to the inflection point. It need hardly be added that the surface tension forces under discussion in this work refer to the larger quantities of interfiber free water in the wet web and not to the surface tension forces commonly associated as a forerunner of actual interfiber bonding in the later stages of water removal. These latter are the residues of water situated at the juncture between adjacent portions of two fibers.

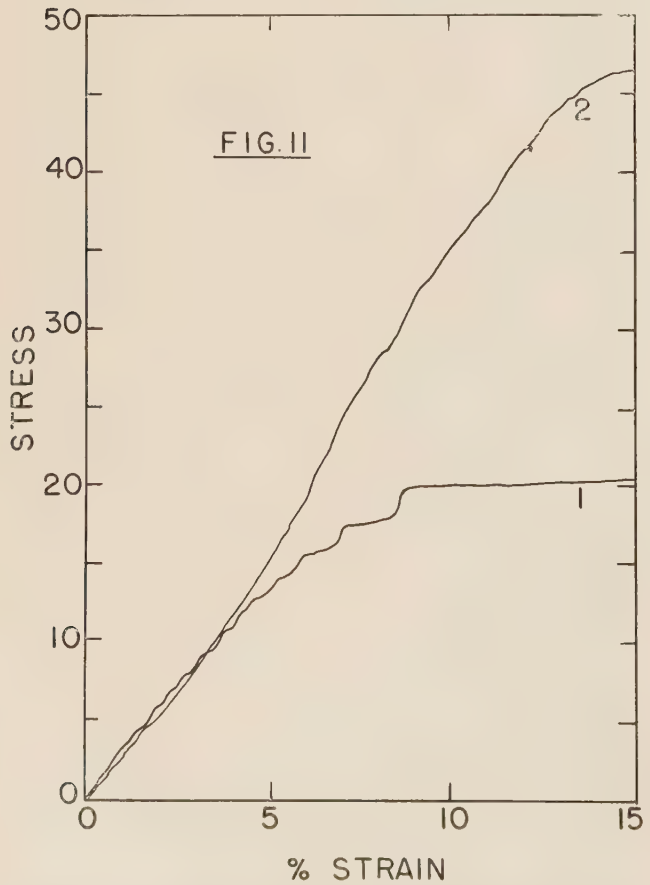

Fig. 11. Autographic stress-strain curves for a glass fiber web with and without reduction of surface tension

It appears altogether likely also that the concept of what might be termed a "network" of water interspersed with a network of fibers admits of readjustments of both structures as water removal proceeds. A subsequent publication will describe an investigation into the rheological properties of these wet webs, but a single illustration of such readjustments at one given moisture content during stressing may be noted as an indirect example. Figure 11 shows a typical stress-strain curve for a glass fiber web consisting of fibers 0.25 mu diameter in an aqueous medium having a surface tension of 39 dynes (curve 1). The curve proceeds in stepwise fashion, with virtually vertical and horizontal components. This must be interpreted as successive stages of almost infinite and zero friction in the system. The stressing in this system is accompanied by a series of audible squeaks similar to that heard on bending a dry glass fiber web when held near the ear. These noises were directly related to the points in the curve at the beginning of each horizontal or "free-flowing" component of the curve. It would appear that on stressing, the system flows readily with negligible increase in stress until a regrouping of forces and structure occurs leading to a system resembling a solid. There is little further strain for a considerable increase in stress. Then the system suddenly "gives" with an audible sound, and the cycle is repeated. The steps increase in magnitude as stressing proceeds. Curve 2 shows that in a similar web with a surface tension of 72 dynes, some indication of this unusual phenomenon may be detected, but that the effect is small. Nevertheless, it might be surmised that this stress-strain curve consists of a very large number of very small steps in comparison with that shown for the medium of reduced surface tension.

It should be emphasized that water removal in all of this work was effected mainly by air-drying accompanied by a very small amount of wet pressing. Details of the procedure have been described elsewhere (2). This procedure was chosen partly in an effort to simulate the state of the web at the couch gap of the paper machine, and also in order to investigate wet pressing as a distinct factor in the investigation. Similarly, only unbeaten pulps are considered above, and the effect of beating will be dealt with as an added factor in a subsequent communication.

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The Aerobic and Benthal Oxygen Demand of Paper Mill Waste Deposits

NICHOLAS J. LARDIERI

The oxygen demand of sludge deposits resulting from paper mill waste discharges were studied under aerobic and simulated stream (benthal) conditions. A constant flow apparatus for studying benthal decomposition in the laboratory is described. The pH values of the paper waste sludge deposits studied were found to be under pH 5.0 and were not found to rise when decomposing under benthal conditions. These low values are considered to be responsible for the low and constant rates of oxygen utilization observed and the small amounts of gas produced during 150 days of benthal decomposition of these deposits. Adjustment of the pH to 7.0 and buffering of the deposits produced approximately a 100% increase in oxygen utilization and a threefold increase in gas production.

In recent years the pulp and paper manufacturing industries have become increasingly conscious of stream pollution problems. Through the National Council for Stream Improvement of the Pulp, Paper and Paperboard Industries Inc., and their own investigations and research, many data have been accumulated concerning the effect of paper mill waste discharges on streams. Oxidation characteristics of the various types of paper mill effluents and the self-purification rates of many streams into which these wastes are discharged have been determined.

While much work has been done on the effect of paper mill waste waters on the flowing portion of the stream, there has been little research on sludge deposits resulting from mill discharges. There is a scarcity of research on the entire problem of sludge deposits whether of domestic or industrial origin. Sludge deposits have a decided effect on stream condition. They can present a greater problem than the flowing pollution load in that an intense oxygen demand may be established in a relatively short stretch of stream.

The interest of the National Council in this question led to the establishment of a research fellowship in the Department of Sanitation, Rutgers University. Studies were made on the decomposition rates of cellulosic sludge deposits with particular emphasis on the oxygen demand of these materials. A number of different sludges were used including alpha-cellulose, white water sludge, groundwood, and those from actual stream deposits. The experiments reported in this paper are limited to those from stream deposits.

NATURE OF BENTHAL DECOMPOSITION

Stabilization of sludge deposits in streams occurs through a combination of aerobic and anaerobic mechanisms. The over-all process has been termed "benthal decomposition." A simplified diagram of the reactions taking place in benthal decomposition is shown in Fig. 1. The surface layer of the sludge deposit, as well as the soluble decomposition products resulting from anaerobic decomposition in the lower layers which diffuse into the aerobic zone, is decomposed aerobically. The depth to which this aerobic zone extends will depend on the amount and nature of the sludge deposited and the rate at which it is decomposing. A high demand for oxygen by the deposit may cause a depletion of dissolved oxygen for a considerable depth above the surface of the sludge.

Experiments with sewage sludges indicate that a considerable percentage of sludge bank stabilization (depending on the deposit depth) occurs through anaerobic action (*1*). The ultimate products of anaerobic action are gases (principally methane and carbon dioxide) which escape to the atmosphere and thus do not exert any demand on the oxygen dissolved in the overlying water. The greater the proportion of organic matter that is converted to these gases, therefore, the less will be the depletion of the stream's dissolved oxygen resources due to the deposition of a given amount of decomposable organic matter.

METHODS AND PROCEDURES USED

It is extremely difficult to study sludge deposits under actual field conditions due to the rapid changes which often occur in streams. The many variables in streams such as flow velocity, turbulence, and temperature to mention but several, can be controlled with the use of laboratory techniques. With these laboratory methods it is possible, therefore, to measure certain effects produced by these deposits.

The laboratory equipment used in these experiments to determine benthal decomposition rates is simple in construction and operation and does provide a measure of the oxygen demand exerted and gas produced by these deposits. It is felt that the apparatus has several advantages over those respirometers used in previous benthal studies although it is similar in principle (*1*).

The apparatus is pictured in Fig. 2. A 4-liter aspirator bottle in which a double U-tube was placed served as a constant head reservoir from which a length of glass capillary tubing delivered oxygen saturated water immediately above the sludge surface. Two-inch diameter lucite tubes were used to contain the sludge. These tubes were terminated approximately 1 in. above the top of the sludge. The water after passing over the deposit was discharged without aeration into a dissolved oxygen determination bottle. The contents of this bottle were displaced a minimum of ten times before the dissolved oxygen was determined. A gasom-

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eter was attached to the air-tight cylinder containing the decomposing sludge.

This system maintains constant flow; the rate of which may be changed most simply by raising or lowering the elevation of the discharge bottle. By determining the dissolved oxygen content of both the influent and effluent water, it was possible because of the known rate of flow to obtain the measure of the oxygen used by the deposit in a given length of time. The amounts of oxidizable materials discharged to the liquid phase were determined by using the standard biochemical oxygen demand (B.O.D.) test.

The rate of oxygen utilization by sludge deposits under completely aerobic conditions was determined by manometric methods. The Sierp apparatus was found to be especially suited for oxidation measurements of this type. Much larger quantities of sludge (0.5 to 1.0 grams) can be used than in the dilution method of determining B.O.D. The conditions of rapid agitation in an atmosphere of pure oxygen and the ability to closely and continuously observe the course of oxidation are further advantages of this method.

All experiments were conducted at 20°C.

AEROBIC OXYGEN DEMAND OF SLUDGE DEPOSITS

The sludge deposits used in these experiments were obtained from a pool behind a dam. The river discharging into the pool contains cellulose fiber from paper mills together with some domestic sewage. At the time the first sample was taken the water depth was about 20 ft. and the flow velocity approximately 1 mile per day. The water had a temperature of 21°C., pH 6.3, and dissolved oxygen content of 3.0 p.p.m. The sludge was obtained from a floating layer which had risen and may be considered to be representative of material found in the upper strata of the deposit.

The sludge had the following characteristics:

Total solids, %	9.9
Total volatile solids, %	5.0
Volatile solids, %	49.3
pH	4.9

The oxygen utilization rate of the sludge as determined in the Sierp apparatus is shown in Fig. 3. In 141 days the total demand was found to be 710 mg. of oxygen per gram of volatile solids. There is a linear rate of oxygen demand for a period of more than 100 days after which the demand is decreased.

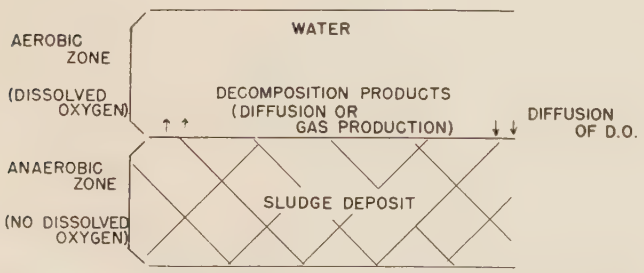

Fig. 1 Graphic representation of reactions occurring in sludge bank decomposition

An increase in pH occurred as the sludge is oxidized aerobically. From an original pH of 4.9, it rose to 6.6 after 105 days and 6.9 at 141 days.

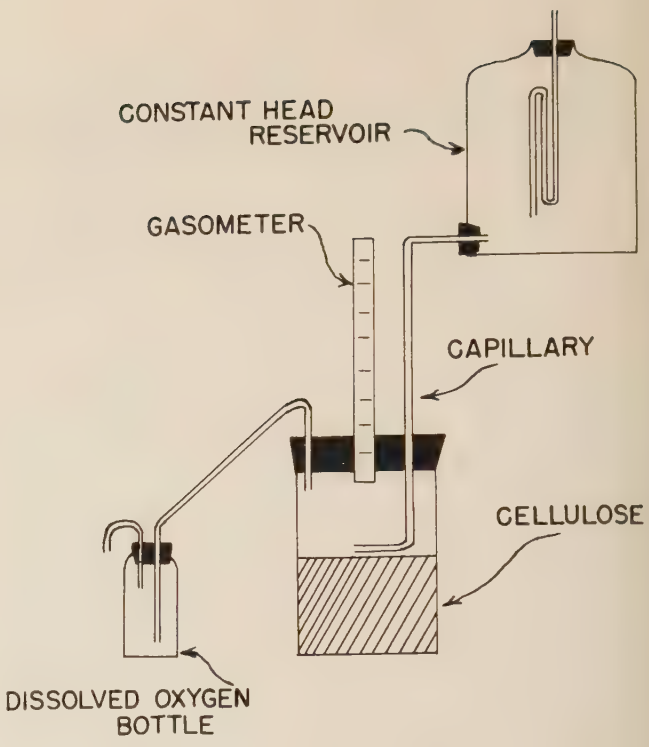

Fig. 2. Continuous flow apparatus for determining benthal decomposition rates of sludge deposits

Effect of pH and Sludge Depth on Aerobic Oxygen Demand

In order to determine the aerobic oxidation rates of sludge from different depths in a deposit, samples were obtained from the 1- and 5-ft. depths. These samples were taken from the same pool approximately 1 year after that whose oxidation rate is shown in Fig. 2. The characteristics of the material from the two strata are given in Table I.

Table I. Analysis of Material at Upper and Lower Levels in a Sludge Deposit

	Upper strata	*Lower strata*
Depth, ft.	1	5
Total solids, %	9.9	12.0
Total volatile solids, %	4.9	3.7
Volatile solids, %	49.4	30.6
pH	4.3	4.4

The above sludges were oxidized under strictly aerobic conditions for a period of 35 days. Duplicate samples of each were also adjusted to pH 7.0 with sodium hydroxide, buffered with calcium carbonate, and then oxidized.

The results of this series of experiments are shown in Fig. 4. Sludge from the upper and lower strata utilized 91.2 and 105.0 mg. of oxygen per gram of volatile solids, respectively, when oxidized without pH adjustment. The values for the same sludge with pH adjustment and buffering were 175.6 and 202.5 mg. of oxygen per gram of volatile solids for the upper and lower strata, respectively. While there is some irregularity at the start of the unadjusted oxidations, the oxygen demand curve for both sets is essentially similar.

During the oxidation of the original sludges, the pH strata to 4.9 after 35 days in both the upper and lower rose samples, while the final pH values in the adjusted

sludges were 7.2 and 7.7 for the upper and lower strata, respectively. An adjustment in pH from 4.3 to 7.0 and buffering with calcium carbonate causes an increase in the oxygen demand of approximately 100% in 35 days. As was the case with the unadjusted samples,

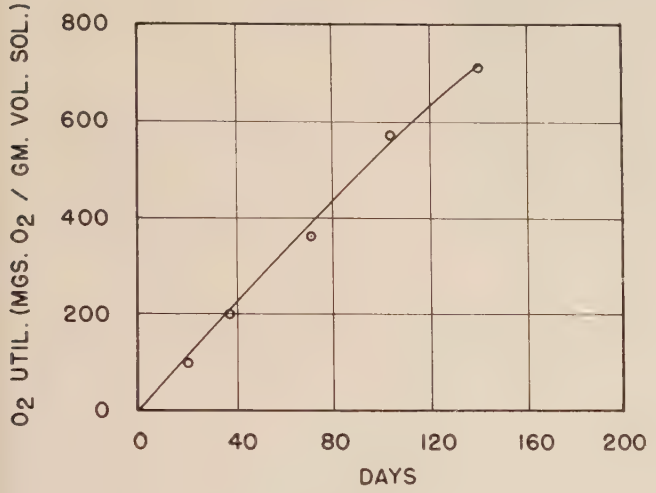

Fig. 3. Aerobic oxygen demand of a paper mill waste deposit

the upper and lower strata sludges have practically the same oxidation curve and oxygen demand for 35 days.

BENTHAL OXYGEN DEMAND OF SLUDGE DEPOSITS

Effect of Sludge Depth on Oxygen Demand

The relationship of sludge depth to the oxygen demand of sludge deposits was determined on the sludge whose aerobic oxidation curve has been shown in Fig. 3. Three depths of sludge were used: 3.8, 8.1, and 16.0 cm.; and their oxygen demand was followed for 85 days under continuous flow conditions. The results of this series of experiments are summarized in Table II, and the oxygen utilization curves shown in Fig. 5.

Table II. Benthal Oxygen Demand of Paper Waste Sludge Deposits

Depth of deposit, cm.	3.8	8.1	16.0
Total volatile solids in deposit, grams	3.1	6.2	12.4
Oxygen demand, mg. oxygen/g. vol. sol.			
Sludge (in place)	122.0	62.2	41.5
Effluents	67.0	49.7	27.7
Total	189.0	111.9	69.2
pH of deposit			
Initial	4.9	4.9	4.9
Final	4.3	4.5	4.7

A distinction was made in the oxygen demand results between the immediate oxygen demand (in place) and the oxygen demand of the leachings which were determined outside the benthal unit in B.O.D. bottles. The sludge oxygen demand values for the depths of 3.8, 8.1, and 16.0 cm. were 122.0, 62.2, and 41.5 mg. of oxygen per gram of volatile solids, respectively, while the oxygen demand of the leachings were 67.0, 49.7, and 27.7 mg. per gram for these depths.

The pH values of the deposits were determined at several intervals. After 39 days the pH in the shallowest depth had dropped from 4.9 to 4.6 and from 4.9 to 4.4 in each of the deeper deposits. At the end of 85 days the pH values in the deposits were 4.3, 4.5, and 4.7 for the 3.8, 8.1, and 16.0-cm. sludges, respectively. During this period of 85 days there were no measurable amounts of gas produced from the deposits.

Effect of pH on Benthal Oxygen Demand

The benthal stabilization on the series described immediately above was followed through 96 days. At that point the 8.1-cm. deposit was continued without change. The 16.0-cm. deposit was divided into two equal portions after the pH had been adjusted to 7.5 with NaOH and 12.5 grams of powdered $CaCO_3$. To one of these two adjusted samples, 1 gram of highly stabilized, dried, and powdered activated sludge solids was added. The purpose of this experiment was to ascertain what effect pH had on oxygen demand, and also to determine whether the additional source of nitrogen and other nutrients contained in activated sludge would produce any change in rate. Benthal oxidation under these conditions was continued for 67 days.

The oxygen demand rates for the adjusted sludges are compared with the original sludge in Fig. 6. There is no difference in the oxygen utilization of the adjusted sludges; these values being 129.0 and 128.0 mg. of oxygen per gram of volatile solids in 67 days for the pH adjusted and pH adjusted plus activated sludge solids units respectively. This compares with a value of 134.0 mg. per gram for the unadjusted solids in over twice the length of time, 156 days.

Considerably more gas is produced in the adusted sludges. The total gas collected from the original sludge was 60 ml. in 156 days while 110 and 162 ml. were collected from the pH adjusted and activated sludge solids deposits, respectively, in 67 days. The addition of $CaCO_3$ is not entirely successful in maintaining the pH at neutrality; values of 6.4 being recorded in both adjusted sludges after 67 days.

DISCUSSION OF RESULTS

The aerobic and benthal oxidations of unneutralized paper mill waste deposits are characterized by linear

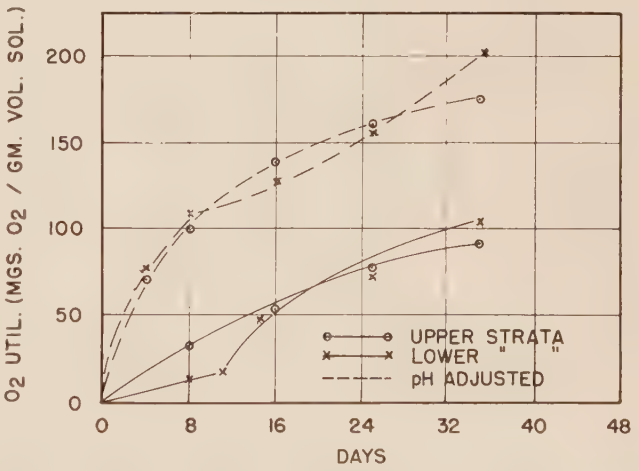

Fig. 4. Effect of depth of sludge and pH on the aerobic oxygen demand of paper mill waste deposits

rates of oxygen demand (Figs. 3 and 5). The oxygen demand of these cellulosic materials remains constant until the oxidation is almost complete. In this respect, the decomposition of paper sludge deposits differs from the behavior of sewage sludges whose oxygen demand continually decreases with time.

It is believed that the most important reasons for this difference in oxidation characteristics are the low pH and the nature of the material undergoing decomposition. Experiments with pure alpha-cellulose fiber also show approximate linear rates even when oxidation conditions are optimum. In the case of the actual paper waste sludge deposits which are more heterogeneous mixtures, the pH factor is probably predominant in controlling the rate of oxidation. This is evidenced by the increased oxidation and nonlinear type of oxygen demand which results when the pH is adjusted and maintained closer to neutrality (Figs. 4 and 6). The pH adjusted oxidation for the upper strata sludge is a logarithmic curve. The low pH values which were consistently found in both the aerobic and benthal experiments may be considered to cause a permanent "lag" phase in the decomposition process. It is likely that only a small number of specialized organisms can thrive under these acid conditions.

The oxygen utilization curves obtained for the upper and lower strata (Fig. 4) samples are a further indication that the decomposition in these acid sludge deposits proceeds at retarded and constant rates. Sludge from the 1 and 5-ft. levels shows the same oxygen demand per gram of volatile matter despite the lower percentage of volatile solids in the lower strata. Some of this lower percentage may be due to greater admixture with inorganic matter (silt) at the 5-ft. level, but it seems likely that a greater proportion of the difference in the two levels is due to volatile matter destruction. The accumulation of a 5-ft. sludge deposit takes a considerable length of time. Despite the fact that the bottom layers in the deposit are composed of what is older material, its oxygen utilization per unit weight of volatile solids is the same as sludge deposited much more recently.

The benthal oxygen demand of paper waste deposits is much less than the aerobic oxygen demand; and decreases markedly per unit weight of solids deposited

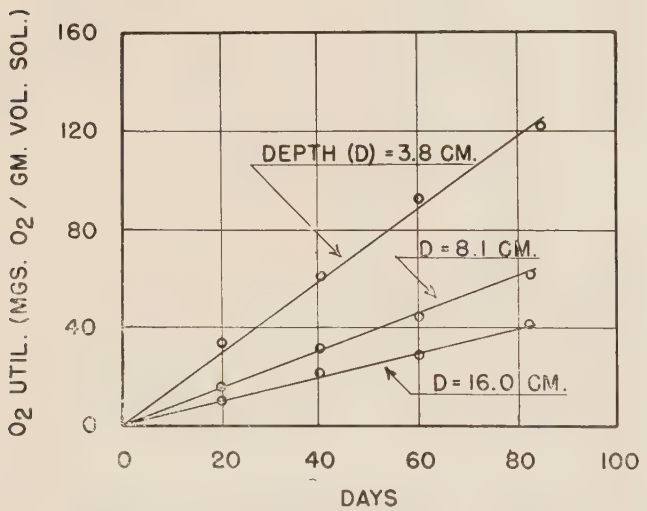

Fig. 5. Effect of sludge depth on benthal oxygen demand

with increasing depth. The aerobic oxygen demand in 85 days as shown in Fig. 3 is approximately 500 mg. of oxygen per gram of volatile solids as compared with values of 189.0, 111.9, and 69.2 for deposits of 3.8, 8.1, and 16.0 cm. It can also be seen that the oxygen utilization per unit amount of volatile solids is about

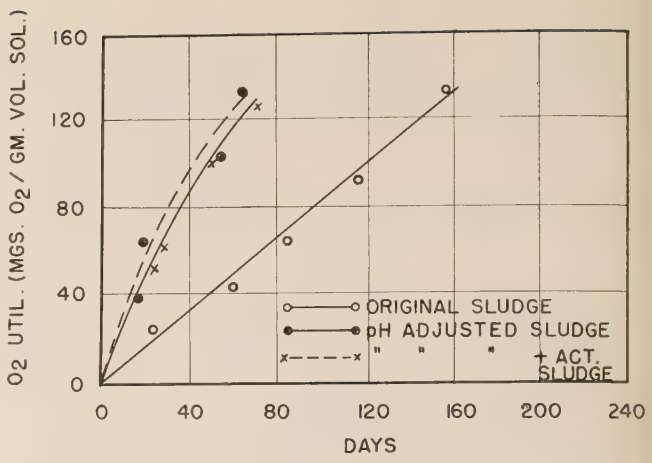

Fig. 6. Effect of pH on benthal oxygen demand

three times as great in the 3.8-cm. deposit as it is in the 16.0-cm. deposit. The major portion of the decomposition is probably occurring at the sludge-water interface where the conditions such as oxygen availability and pH are more conducive to biological oxidation. The extremely small amount of gas produced while the material was being decomposed in its original state indicates that the pH is too low to support active cultures of methane-producing organisms. That this is the case is shown by the increase in gas production from 60 ml. in 156 days in a normal deposit to 110 ml. in 67 days when the sludge pH was adjusted to 7.5. It is not known whether the further increase in gas production caused by the addition of the activated sludge solids is due to a stimulatory effect or the actual gasification of these solids.

SUMMARY AND CONCLUSIONS

The oxygen demands of sludge deposits resulting from the discharge of paper mill wastes were studied under aerobic and simulated stream (benthal) conditions. The results obtained indicate:

1. The pH values of paper waste sludge deposits studied were found to be under 5.0.

2. The low pH in the deposits is responsible for the low and constant rate of benthal oxygen utilization observed.

3. There are relatively small amounts of gas produced due to the low pH which retards the activities of methane-producing bacteria.

4. Adjustment of paper deposit sludges to a pH of 7.0 causes an increase of approximately 100% in oxygen demand in both aerobic and benthal decomposition. Gas production is more than doubled after such adjustment.

5. The oxygen demands of bottom and lower strata sludge from a 5-ft. deposit were identical per unit weight of volatile solids, evidence that decomposition in these acid deposits proceeds at low and constant rates.

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ASSOCIATION NEWS AND EVENTS

Local Section Meetings

Pacific: Jan. 11, 1955, Longview, Wash., Pulping Session; March 4, 1955, Everett, Wash., Shibley Award Program; May 18–21, 1955, Empress Hotel, Victoria, B. C.

Kalamazoo Valley: Jan. 13, 1955, Harris Hotel, Kalamazoo, Mich., joint meeting with Michigan Division APPM Superintendents Association. Feb. 3, 1955, "The Technical Man Looks at Practical Mill Problems—Bleaching," by Stephen Kukolich, Lee Paper Co., Vicksburg, Mich., and "Stock Treatment," by W. F. Hathaway, Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich.

Southeastern: Jan. 14–15, 1955, Francis Marion Hotel, Charleston, S. C., general subject "Pulpwood"; visit to the mill of the West Virginia Pulp & Paper Co.; March 18–19, 1955, George Washington Hotel, Jacksonville, Fla.; May 13–14, 1955, De Soto Hotel, Savannah, Ga.

Chicago: Jan. 17, 1955, Chicago Bar Association Rooms, Chicago, Ill.; March 21, 1955; April 18, 1955; May 16, 1955.

Lake States: Jan. 11, 1955, Dinner at Conway Hotel, Appleton, Wis., meeting at The Institute of Paper Chemistry, "Chromatography for Control and Research in Pulp and Paper," by Edgar Dickey, Institute of Paper Chemistry; March 8, 1955, Elks Club, Kaukauna, Wis., afternoon visit to the mill of the Thilmany Pulp & Paper Co., Kaukauna, Wis.; April 12, 1955, Conway Hotel, Appleton, Wis., Clarence J. West Memorial Award Program; May 10, 1955, annual meeting.

New England: March 25, 1955, Statler Hotel, Hartford, Conn.; June 3–4, 1955, Oceanside House, Magnolia, Mass., annual meeting.

Ohio: Jan. 11, 1955, Hotel Manchester, Middletown, Ohio, "Stock Preparation," by Alfred H. Nadelman, Western Michigan College, Kalamazoo, Mich.; Feb. 10, 1955, American Legion Hall, Middletown, Ohio, "A Comparison of Printing Processes," by Marvin C. Rogers; March 8, 1955, Manchester Hotel, "Use of Optical Instruments," by Richard H. Hunter; April 14, 1955, American Legion Hall, Panel Discussion on use of pigments; May 12, 1955, C. G. & E. Co., Hartwell Clubhouse, Cincinnati, Ohio, annual meeting.

Lake Erie: Jan. 14, 1955, Carter Hotel, Cleveland, Ohio, "Materials Handling"; Feb. 11, 1955, "Industrial Psychology"; March 11, 1955, "Measurement and Control in the Graphic Arts"; April 15, 1955, "Recent Development in Printing Inks"; May 13, 1955, open.

Delaware Valley: Jan. 27, 1955, Engineers Club, Philadelphia, Pa., Graphic Arts Meeting, joint meeting with the Philadelphia Printing Ink Makers' Production Club (Panel Discussion); March 24, 1955, "Paper Mill Management," by K. O. Elderkin, Bowaters Southern Paper Corp., Calhoun, Tenn.; May 26, 1955, Edward J. Albert Award Competition.

Empire State: June 9–11, 1955, Whiteface Inn, Lake Placid, N. Y.

Empire State (Metropolitan District): Jan. 11, 1955, Fraunces Tavern, New York, N. Y., "Comparison of Various Pulps from a Use Aspect," by Gerald Haywood, West Virginia Pulp & Paper Co., Luke, Md.; March 8, 1955, Panel Discussion on Printing; April 12, 1955, "Fundamentals of Stock Preparations"; May 10, 1955, annual meeting.

Empire State (Northern District): Jan. 13, 1955, Woodward Hotel, Watertown, N. Y.; Feb. 10, 1955; March 10, 1955; April 14, 1955, Empire State Section Award Papers; May 12 1955, annual meeting.

Empire State (Western District): Feb. 2, 1955, visit to J. W. Clement Co. plant in Buffalo, N. Y.; March 8, 1955, joint meeting in Canada with the CPPA Technical Section Niagara Branch; April 6, 1955, Suppliers Night, "Availability of Raw Materials"; May 4, 1955, Lockport, N. Y., annual meeting.

Empire State (Eastern District): Jan. 20, 1955, Glens Falls, N. Y.; Feb. 17, 1955; March 17, 1955; April 21, 1955; May 21, 1955, annual meeting.

Empire State (Central District): Jan. 7, 1955, University Club, Syracuse, N. Y., "Waste Paper Utilization"; Feb. 4, 1955, "Screening," by H. F. Schenk, Magnus Metal Co., Fitchburg, Mass.; March 4, 1955, "New Developments in Paper Machine Design," by Earl H. Swartz, Beloit Iron Works, Beloit, Wis.; April 2, 1955, "Interesting Developments in Titanium Research," by H. C. Brill, Pigments Dept., E. I. du Pont de Nemours & Co., Inc., Newark, Del.; May 6, 1955, New York State College of Forestry Seniors Night; June 3, 1955, annual meeting.

Maine-New Hampshire: To be announced.

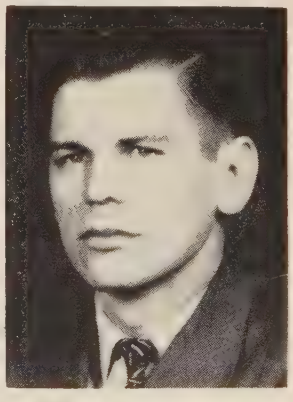
TAPPI Annual Meeting

The Annual Meeting of the Technical Association of the Pulp and Paper Industry will be held at the Commodore Hotel, New York, N. Y., on Feb. 21–24, 1955. Registration will begin on Sunday, February 20, at 4:00 p.m. and will continue until 8:00 p.m. Members of the Association are reminded to have their 1955 membership cards with them at the time of registration. A higher registration fee will be charged nonmembers who register for the meeting All individuals attending the Annual Meeting or occupying rooms at the Commodore during the meeting are required to register. Several company representatives attending previous meetings have failed to register.

The Association does not feature exhibits of equipment at the meeting on the meeting room floor. Unusual exhibits on the ballroom floor are occasionally permitted. Permission of the Association and the Commodore Hotel are required for any exhibit of equipment.

Mill Maintenance and Materials Committee

Louis L. Mrachek, division engineer of The Mead Corp., Kingsport, Tenn., has been appointed chairman of the TAPPI Mill Maintenance and Materials Committee succeeding George Hrubecky of the Marathon Corp., Menasha, Wis., deceased. During the Ninth Engineering Conference, Hubert F. Parker of the New York & Pennsylvania Co., Lock Haven, Pa., served as acting chairman.



L. L. Mrachek, The Mead Corp.; Chairman, Mill Maintenance and Materials Committee

Second Mechanical Pulping Conference

The second international Mechanical Pulping Conference will be held at Poland Spring House, Poland Spring, Me., Sept. 19–21, 1955, and will be jointly sponsored by the Technical Section of the Canadian Pulp and Paper Association and the Technical Association of the Pulp and Paper Industry.

Thomas F. LaHaise, Jr., Imperial Paper and Color Corp., Plattsburg, N. Y., general chairman for the conference, is being assisted by a joint committee drawn from the Mechanical Pulping Committees of the two sponsoring associations. The technical program is being prepared by a subcommittee consisting of J. H. White, Keyes Fibre Co., Waterville, Me., W. H. de Montmorency, Pulp and Paper Research Institute of Canada, Montreal, Que., and Foster Fulton, Consolidated Paper Co., Shawinigan Falls, Que. Publicity is being handled by James H. Perry, Norton Co., Worcester, Mass. The chairmen of the two sponsoring committees are T. G. Rust, Quebec North Shore Paper Co., Baie Comeau, Que., and F. W. O'Neil, College of Forestry, State University of New York, Syracuse, N. Y.

Beginning on Monday, Sept. 21, 1955, the three-day technical program will feature regional comparisons of equipment and techniques used for the grinding and screening of mechanical pulp for various specific end uses. Panels drawn from the South, the Northeast, the West, and from Canada will compare notes as to types of grinders, stone composition, burring pattern, screening system, and methods of operation used to make stock for news and hanging, toweling and tissue, book and board, and insulating grades. On Thursday, September 22, delegates will visit mills of interest in the Maine area.

Institute of Statistics

The Institute of Statistics at North Carolina State College, Raleigh, N. C., is sponsoring a nine-day intensive program in statistical methods for research workers in industry and physical sciences starting Jan. 22, 1955, and running daily, including Sundays through Jan. 30, 1955. The course is designed to make available to research workers the new and powerful statistical techniques of data analysis and experimental design. Details may be obtained from the Institute of Statistics, North Carolina State College, Box 5457, Raleigh, N. C.

British Paper & Board Association

The 69th General Conference of the Technical Section of the British Paper & Board Association will be held in the Connaught Rooms, Great Queen St., London W.C. 2, England, on March 23–24, 1955. The subject to be discussed is "Water Procurement, Utilization and Disposal in Paper and Board Mills." A reception for overseas visitors will be held on the evening of Tuesday, March 22. The chairman will give a luncheon on March 23 and a dinner on the evening of the 23rd. All visitors will be invited to these functions.

Research Appropriations Committee

The members of the TAPPI Research Appropriations Committee are also organized on a rotation basis.

The terms of the following members will expire during the Annual Meeting of the Association on Feb. 24, 1955: W. F. Gillespie, Gaylord Container Corp., Bogalusa, La.; J. W. Hemphill, Johns-Manville Sales Corp., New York, N. Y., and J. D. Malcolmson, Robert Gair Co., Berkeley, Calif.

They will be succeeded in February by P. F. Neumann, Hercules Powder Co., Wilmington, Del.; G. W. E. Nicholson, Union Bag & Paper Corp., New York, N. Y., and George H. Pringle, The Mead Corp., Chillicothe, Ohio.

The members of the committee whose terms continue are A. L. Sherwood, Sutherland Paper Co., Kalamazoo, Mich.; W. H. Swanson, Kimberly-Clark Corp., Neenah, Wis.; K. P. Geohegan, Howard Paper Mills, Dayton, Ohio; C. C. Heritage, Weyerhaeuser Timber Co., Tacoma, Wash.; James d'A. Clark, Longview, Wash.; W. W. Moyer, Crown Zellerbach Corp., Camas, Wash., together with the president and vice-president of the Association, *ex-officio*.

Anatomy of Common Pulpwood Barks

"Anatomy of Common North American Pulpwood Barks," TAPPI Monograph No. 14, has been issued to the members of the Technical Association of the Pulp and Paper Industry.

This remarkable publication was prepared under a Technical Association Research Grant by Ying-pe Chang, sponsored by the TAPPI Fundamental Research Committee in cooperation with the Forest Products Laboratory, Madison, Wis.

Twenty common North American pulpwood barks were examined to determine their basic structure and the significant character of their tissues and tissue elements. One hundred and fifty illustrations are included to supplement the text.

Mr. Chang has had about seventeen years' experience in the general field of botanical research and specifically wood technology. In 1946–47 he was a graduate student under the forest products program at the Yale Forestry School from which he received his M.S. degree in 1948. From 1947 to 1949 he was a graduate student at the University of Michigan, School of Forestry. In June, 1949, the Ph.D. degree was conferred upon him and since then he has been a collaborator of the U. S. Forest Products Laboratory working on the anatomy of coniferous barks. Mr. Chang is a nonresident alien who cannot return to China. Until 1952 he was sponsored by the U. S. Dept. of State. The facilities and equipment for his work were supplied by the Forest Products Laboratory.

Editorial Board

The Editorial Board of *Tappi* is organized on a rotating basis with the terms of one third of the members expiring at the end of each year.

The members of the Board whose terms expire at the end of 1954 are A. E. Montgomery, D. G. Moon, J. L. Parsons, Henry Perry, A. L. Sherwood, Edwin Sutermeister, G. H. Tomlinson II, and B. L. Wehmhoff.

Their successors to serve three-year terms ending in 1957 are the following:

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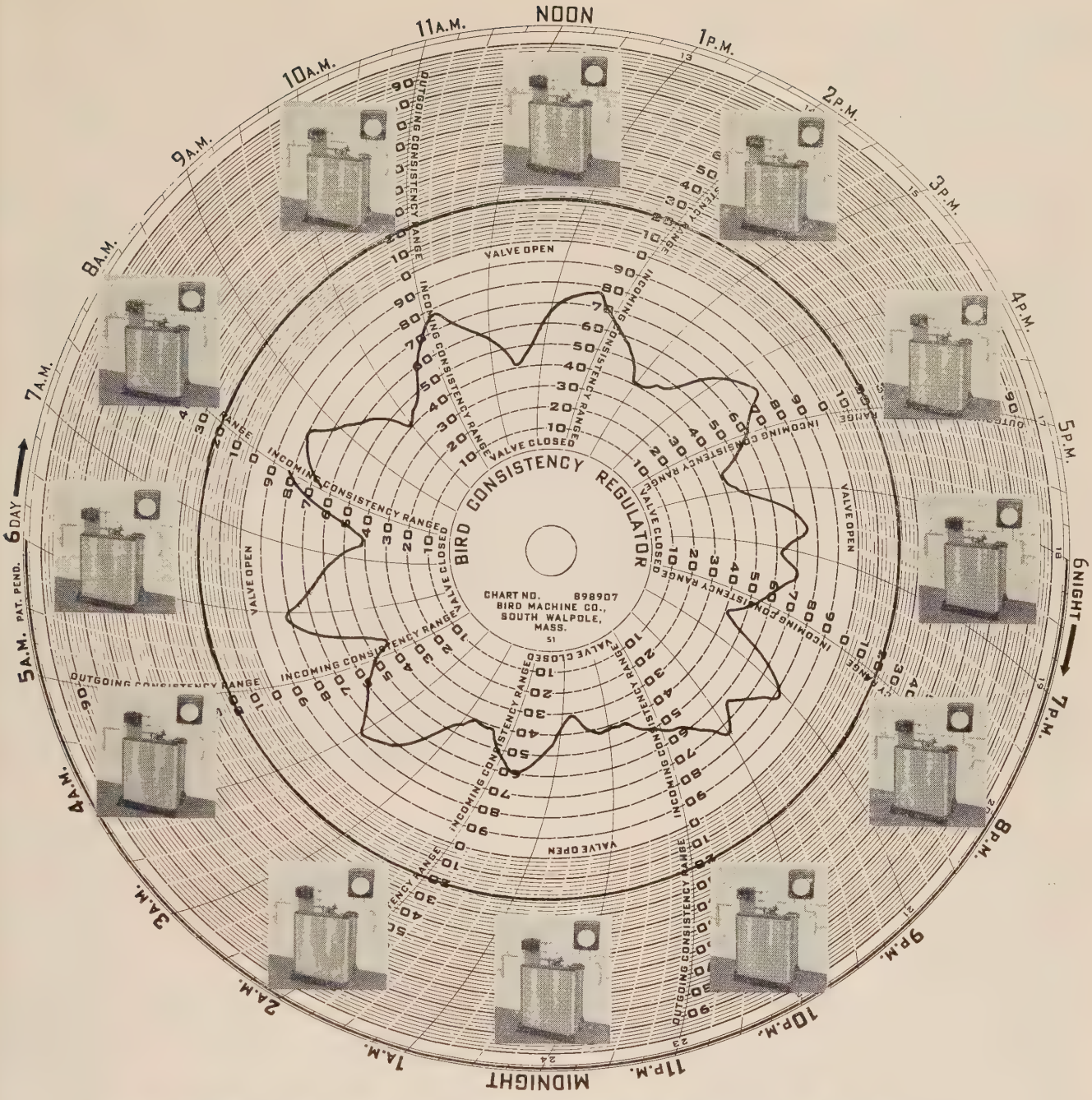
Forest A. Simmonds, Forest Products Laboratory, Madison, Wis.
K. Austin Taylor, International Paper Co., Glens Falls, N. Y.
Curt A. Young, Riegel Paper Corp., Milford, N. J.

TAPPI 40th Annual Meeting

The 40th Annual Meeting of the Technical Association of the Pulp and Paper Industry will be held at the Commodore Hotel, New York, N. Y., on Feb. 21–24, 1955.

Members of the Association should remember to bring their 1955 membership cards with them since the lower registration fee will be limited to individuals who can present their



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1955 cards. All individuals attending the Annual Meeting must register.

MONDAY, FEBRUARY 21, 1955

9:30 a.m. First General Session (East Ball Room)

G. H. Pringle, President of TAPPI, Mead Corp., Chillicothe, Ohio, *Chairman*

1. Secretary's Report, by R. G. Macdonald.
2. President's Address, by George H. Pringle.
3. Report of the Tellers Committee.
4. Report of the Joint Textbook Committee, by R. S. Kellogg, *Secretary*.
5. "Research Facilities at Lowell Technological Institute," by John Lewis, Professor & Head, Dept. of Paper Engineering, Lowell Technological Institute, Lowell, Mass.
6. "A New Dry Felting Process for Making Tissues, Batts, and Boards," by Bror E. Anderson, A. B. Dick Co., Chicago, Ill., and James d'A. Clark, Consulting Engineer, Longview, Wash.
7. "Use of Paper in the Geodesic Pavillion," by B. Fuller, Consultant, New York, N. Y.

10:00 a.m. Packaging Materials Testing Committee (Room F)

12:30 p.m. Chemical Engineering Committee (Luncheon)

12:30 p.m. Engineering Research and Machine Design Committee (Luncheon)

2:00 p.m. Committee Meetings (Grand Ball Room)

All committee meetings will be held in the Grand Ball Room unless otherwise indicated.

Tables assigned to committees will be designated by table cards.

Research and Development Division (Grand Ball Room)

G. A. Day, Brown Co., Berlin, N. H., *General Chairman*

Statistics Committee—John F. Langmaid, Jr., S. D. Warren Co., Cumberland Mills, Me., *Chairman*
Microbiological Committee—B. F. Shema, W. H. & L. D. Betz Co., Philadelphia, Pa., *Chairman*

Industrial Division (Grand Ball Room)

R. L. Davis, Detroit Sulphite Pulp & Paper Co., Detroit, Mich., *General Chairman*

Nonfibrous Raw Materials Committee—E. N. Poor, Hudson Pulp & Paper Co., Augusta, Me., *Chairman*
Water Committee—A. S. Erspamer, Hollingsworth & Whitney Co., Waterville, Md., *Chairman*
Fibrous Agricultural Residues Committee—S. I. Aronovsky, Northern Regional Research Laboratory, Peoria, Ill., *Chairman*
Structural Fibrous Materials Subcommittees—R. G. Lacey, The Celotex Corp., Marrero, La., *Chairman*

Converting and Consuming Division (East Ball Room)

F. D. Long, Container Corp. of America, Chicago, Ill., *General Chairman*

Graphic Arts—C. A. Morton, West Virginia Pulp & Paper Co., Chicago, Ill., *Chairman* (155 E. 44th St.)
Coating Committee—R. T. Trelfa, Watervliet Paper Co., Watervliet, Mich., *Chairman*
Wet Strength Committee—K. W. Britt, Scott Paper Co., Chester, Pa., *Chairman*
Plastics Committee—R. T. Nazzaro, Westfield River Paper Co., Russell, Mass., *Chairman*
Corrugated Containers Committee—Burt Mendlin, Cornell Paperboard Products, Milwaukee, Wis., *Chairman*

Pulp Manufacture Division (Grand Ball Room)

R. I. Thieme, Scott Paper Co., Anacortes, Wash., *General Chairman*

Alkaline Pulping Committee—M. B. Pineo, Brunswick Pulp & Paper Co., Brunswick, Ga., *Chairman*
Mechanical Pulping Committee—F. W. O'Neil, College of Forestry, State University of New York, Syracuse, N. Y., *Chairman* (Room G, Tues., 9:15 a.m.)
Chemical Products Committee—Arthur Pollak, Consulting Engineer, New York, N. Y., *Chairman*
Pulp Purification Committee—W. H. Rapson, University of Toronto, Toronto, Ont., *Chairman*
Acid Pulping Committee—N. S. Lea, Scott Paper Co., Everett, Wash, *Chairman*
Semichemical Pulping Committee—J. N. McGovern, Parsons & Whittemore, New York, N. Y., *Chairman*
Paper Deinking Committee—J. J. Forsythe, International Paper Co., Niagara Falls, N. Y., *Chairman*
Pulp for Chemical Conversion—F. A. Simmonds, Forest Products Laboratory, Madison, Wis., *Chairman*

Paper Manufacture Division (Grand Ball Room)

H. C. Moore, Beloit Iron Works, Beloit, Wis., *General Chairman*

Preparation of Papermaking Materials Committee—F. S. Klein, Byron Weston Co., Dalton, Mass., *Chairman*
Cylinder Board Committee—Glen T. Renegar, Container Corp. of America, Manayunk, Pa., *Chairman*
Fourdrinier Committee—N. R. Phillips, Riegel Carolina Corp., Acme, N. C., *Chairman*

Testing Division (West Ball Room)

J. P. Casey, A. E. Staley Mfg. Co., Decatur, Ill., *General Chairman*

Nonfibrous Materials Testing Committee—K. H. Williams, Mid-States Gummed Paper Co., Chicago, Ill., *Chairman*
Pulp Testing Committee—F. E. Caskey, Morden Machine Co., Portland, Ore., *Chairman*
Optical Properties Committee—H. E. Obermanns, Hammermill Paper Co., Erie, Pa., *Chairman*
Microscopy Committee—C. E. Brandon, Howard Paper Mills, Dayton, Ohio, *Chairman*
Paper Testing Committee—D. H. Newcomb, Riegel Paper Corp., Hughesville, N. J., *Chairman*
Chemical Methods—A. S. O'Brien, Eastman Kodak Co., Rochester, N. Y., *Chairman*
Wax Testing—W. J. Yates, Shell Oil Co., New York, N. Y., *Secretary*

Note: Reports by all committee chairmen of the Testing Division will be given at this session.

Engineering Division

J. D. Lyall, Armstrong Cork Co., Lancaster, Pa., *General Chairman*

Steam and Power Committee—W. M. Wyburn, Federal Paper Board Co., Bogota, N. J., *Chairman*
Chemical Engineering Committee—L. C. Jenness, University of Maine, Orono, Me., *Chairman*
Corrosion Committee—S. J. Baisch, Thilmany Pulp & Paper Co., Kaukauna, Wis., *Chairman*
Mill Maintenance and Materials Committee—L. L. Mrachek, The Mead Corp., Kingsport, Tenn., *Chairman*
Mill Planning and Economics Committee—R. A. Packard, Hopkinton, Mass., *Chairman*
Engineering Research and Machine Design Committee—R. G. Quinn, Johns-Manville Corp., Manville, N. J., *Chairman*
Electrical Engineering Committee—M. J. Osborne, Bowaters Southern Paper Corp., Greenville, S. C., *Chairman*
Data Sheets Committee—J. W. Hemphill, Johns-Manville Corp., New York, N. Y., *Chairman*
Drying and Ventilating Committee—C. A. Young, Riegel Paper Corp., Milford, N. J., *Chairman*
Industrial Engineering and Materials Handling Committee—J. M. MacBrayne, Union Bag & Paper Corp., Savannah, Ga., *Chairman*

TUESDAY, FEBRUARY 22, 1955

9:15 a.m. Deinking (Room B-C)

J. J. Forsythe, International Paper Co., Niagara Falls, N. Y., *Chairman*

1. "The Ahlfors Screen," by F. Schorken, Oliver United Filters, Inc., Oakland, Calif.
2. "Cleaning Deinked Stock with Centri-Cleaners," by J. L. Clouse, Oxford Miami Paper Co., West Carrollton, Ohio, and E. Rastatter, Bauer Bros. Co., Springfield, Ohio.

9:15 a.m. Engineering (Grand Ball Room)

J. D. Lyall, Armstrong Cork Co., Lancaster, Pa., *Chairman*

1. "Modern Architecture in Pulp and Paper Mills," by Mario C. Celli, Celli-Flynn, McKeesport, Pa.
2. "The Sulzer System for Water Removal," by Robert Thomann, Sulzer Bros., Winterthur, Switzerland.

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3. "Graphical Determination of Roll Deflection," by R. C. Sturken and D. A. Verner, Frank W. Egan Co., Bound Brook, N. J.
4. "Application and Maintenance of Paper Stock Pumps," by E. Schwandt, Goulds Pumps Inc., Seneca Falls, N. Y.

9:15 a.m. Wax Testing (Room A)

9:15 a.m. Mechanical Pulping Committee (Room G)

9:15 a.m. Chemical Methods (Room F)

9:15 a.m. Cylinder Board (West Ball Room)

GLEN T. RENEGAR, Container Corp. of America, Manayunk, Pa., *Chairman*

1. "Stock Cleaning Systems," by P. S. Bolton, Robert Gair Co., Uncasville, Conn.
2. "Development of the Shartle Alligator Refiner," by H. P. Erspenmiller, Black-Clawson Co., Middletown, Ohio.
3. "Vat Exhauster Survey," by Otis Whitworth, Black-Clawson Co., Hamilton, Ohio.
4. "Optimum Use of Top Liner," by W. R. Csellak, Gardner Board & Carton Co., Middletown, Ohio.

9:15 a.m. Pulp Purification (East Ball Room)

W. H. RAPSON, University of Toronto, Toronto, Ont., *Chairman*

9:15 a.m. Characteristics and Properties of Pulp Fibers

JAMES J. d'A. CLARK, Consulting Engineer, Longview, Wash., *Chairman*

12:30 p.m. Corrosion Committee (Luncheon)

2:00 p.m. Structural Fibrous Materials Committee (Room E)

2:00 p.m. Fundamental Research (Room B-C)

H. F. LEWIS, Institute of Paper Chemistry, Appleton, Wis., *Chairman*

1. "The TAPPI-Sponsored Research Activity of the Fundamental Research Committee," by H. F. Lewis, Institute of Paper Chemistry, Appleton, Wis.
2. "The Uronic Acid Components of the Hemicelluloses of Pulpwoods," by J. K. N. Jones.
3. "Composition of Pulpwood Barks," by Ying-Pe-Ching, Forest Products Laboratory, Madison, Wis.
4. "The Effect of Water on Cellulose in the Temperature Range 100 to 225°C.," by W. H. Rapson and B. B. Mithel, University of Toronto, Toronto, Ont.
5. "Dye Adsorption on Wood Pulp, IV. Note on the Effect of Drying of Pulp on Specific Dye Adsorption," by E. F. Thode, A. J. Chase, and Yee Hu, University of Maine, Orono, Me.
6. "Correlation of Dye Adsorption and Cupriethylenediamine Viscosity Tests for Pulp Characterization," by E. F. Thode and J. F. Gorham, University of Maine, Orono, Me.

2:00 p.m. Pulp Purification (South Room)

W. H. RAPSON, University of Toronto, Toronto, Ont., *Chairman*

1. "Chlorine Dioxide and Safety," by J. F. Haller and W. W. Northgraves, Mathieson Chemical Corp., Niagara Falls, N. Y.

2:00 p.m. Water (East Ball Room)

A. THURN, Champion Paper & Fiber Co., Hamilton, Ohio, *Chairman*

1. "Chemical and Biochemical Effluent Purification," by E. Farber and D. V. Robertson, Timber Engineering Co., Washington, D. C.
2. "Water Pollution—Magnetic Abatement," by W. R. Stamen, *Chemical Abstracts*, Columbus, Ohio.
3. "Determination of Carbon Dioxide by Conductimetric Titration," by C. A. Noll and J. W. Polsky, W. H. & L. D. Betz Co., Philadelphia, Pa.
4. "Safe Handling of Paper Mill Chemicals," by H. F. Jacques, Diamond Match Co., Plattsburg, N. Y.
5. "Slime Control Chlorination in Paper Production," by B. J. Twisdale, National Paper Corp. of Pennsylvania, Ransom, Pa.

2:00 p.m. Cylinder Board (West Ball Room)

GLEN T. RENEGAR, Container Corp. of America, Manayunk, Pa., *Chairman*

5. "Weight and Caliper Control," by L. R. Ayers, Robert Gair Co., Piermont, N. Y.
6. "Use of Calender Driers and Smoothing Presses for Improving Finish," by J. J. Higgins, Ohio Boxboard Co., Rittman, Ohio.

2:00 p.m. Chemical Engineering and Corrosion

L. C. JENNESS, University of Maine, Orono, Me., *Chairman*

1. "Properties and Analysis of Inorganic Pulping Solutions," by R. P. Whitney, S. T. Han, R. B. Kesler, and R. S. Couciere, Institute of Paper Chemistry, Appleton, Wis.

WEDNESDAY, FEBRUARY 23, 1955

9:15 a.m. Semichemical Pulping (East Ball Room)

J. N. McGOVERN, Parsons & Whittemore, New York, N. Y., *Chairman*

1. "The Liquor to Wood Ratio as a Variable in NSSC Pulping," by E. L. Keller, U. S. Forest Products Laboratory, Madison, Wis., and J. N. McGovern, Parsons & Whittemore, New York, N. Y.
2. "Cohesive Rating in Semichemical Pulping," by John Hart, Pulp and Paper Research Institute of Canada, Montreal, Que.
3. "A Comparison of the Action of Sodium and Sodium Neutral Sulphite Liquors on Wood Meal," by D. J. MacLaurin, J. E. Stone, and C. Forderreuther, Institute of Paper Chemistry, Appleton, Wis.
4. "The Recovery of Waste Liquors from NSSC Pulping by the Sulfox Process," by A. Pollak and R. S. Aries, Sulfox Corp., N. Y.

9:15 a.m. Dissolving Pulp (Room B-C)

F. A. SIMMONDS, U. S. Forest Products Laboratory, Madison, Wis., *Chairman*

1. "The Relationship of Tire Cord Properties to the Amount of Beta-Cellulose and Resistant Pentosan in the Pulp," by D. D. Bachlott, E. I. du Pont de Nemours & Co., Wilmington, Del.
2. "A Method of Qualifying Dissolving Grade Pulps," by B. G. Hoos, Brown Co., Berlin, N. H.

9:15 a.m. Statistics (South Room)

J. F. LANGMAID, JR., S. D. Warren Co., Cumberland Mills, Me., *Chairman*

9:15 a.m. Preparation of Papermaking Materials (West Ball Room)

F. S. KLEIN, Byron Weston Co., Dalton, Mass., *Chairman*

1. "The Beater Addition of Anionic and Cationic Polyacrylate Latices," by F. C. Leavitt, W. J. Andrews, and V. T. Stannett, University of the State of New York, College of Forestry, Syracuse, N. Y.
2. "The Electrokinetics of Rosin Size," by E. F. Thode, University of Maine, Orono, Me.
3. "The New Jones Refiner," by E. H. Cumpston, S. D. Jones & Sons, Pittsfield, Mass.
4. "The Deculator-Cleaner," by J. C. Stewart and J. A. Smith, Rotareaed Corp., Bronxville, N. Y.

9:15 a.m. Corrugated Containers (Grand Ball Room)

W. D. ARBURTHNOT, Fibre Board Container Corp., Richmond, Va., *Chairman*

1. "Variable-Speed Drive—Principal Advantages and Disadvantages," by F. A. Leser, Jr., Samuel M. Langston Co., Camden, N. J.

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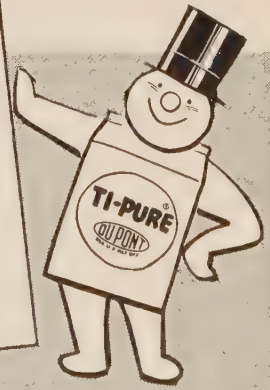

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2. "Moisture Control at Corrugator-Warp Control by Instrumentation on Double Backer," by D. Ellinger, Downing Box Co., Milwaukee, Wis.
3. "Research Project into Machine Design for New Corrugator," by W. Ward, F. X. Hooper Co., Glenarm, Md.

2:00 p.m. Dissolving Pulp (Room B-C)

M. O. Schur, Ecusta Paper Corp., Pisgah Forest, N. C., *Chairman*

Symposium—Filterability

1. "Laboratory Evaluation of Viscose Filterability with Different Filter Media," by L. N. Rogers, Buckeye Cotton Oil Co., Memphis, Tenn.
2. "The Influence of the Filter Medium on the Filtration of Viscose," by L. F. McBurney, Hercules Powder Co., Wilmington, Del.
3. "Characterization of Pulps via Integrated Filtration and Optical Studies on Their Viscoses," by M. Golben, American Viscose Corp., Marcus Hook, Pa.

2:00 p.m. Corrugated Containers (Grand Ball Room)

T. C. West, Hoerner Corp., Southwest Corrugated Box Co., Fort Worth, Tex., *Chairman*

1. "Résumé of Printer-Slotter Questionnaire," by D. P. McNelly, Fort Wayne Corrugated Paper Co., Rochester, N. Y.
2. "Quality Control of Raw Materials," by Ked Martin, Fort Wayne Corrugated Paper Co., Rochester, N. Y.
3. "Printing Die Practices on Printer-Slotter," by A. Sehmidt, Commercial Stamping Co.
4. "Score Profiler," by R. C. McKee, Institute of Paper Chemistry, Appleton, Wis.

2:00 p.m. Statistics (South Room)

J. F. Langmaid, Jr., S. D. Warren Co., Cumberland Mills, Me., *Chairman*

2:00 p.m. Papermaking (Fourdrinier)

N. R. Phillips, Riegel Carolina Corp., Acme, N. C., *Chairman*

1. "Some Viscoelastic Properties of Glassine," by R. T. Nazzaro, W. J. Brand, and S. R. Arnold, Westfield River Paper Co., Russell, Mass.
2. "The Use of Polyamide Resin Suspensoids as Protective Coatings for Paper," by W. F. Brown, University of Florida, Gainesville, Fla.
3. "Application and Maintenance of Paper Stock Pump," by E. Schwandt, Goulds Pumps, Inc., Seneca Falls, N. Y.
4. "Warehousing, Shipping and Materials Handling of Carton Packed Papers," by S. W. Blanchard, Mead Corp., Chillicothe, Ohio.
5. "Pneumatic Clutches in the Paper Mill," by J. S. Walsh, Fawick Airflex Div., Federal Fawick Corp., Cleveland, Ohio.
6. "Remote Control Edge Alignment," by P. W. Jacobsen, H. G. Weber & Co., Kiel, Wis.
7. "A New Concept in Roll Wrapping," by C. S. Adams, Rice Barton Corp., Worcester, Mass.

2:00 p.m. Testing (West Ball Room)

J. P. Casey, A. E. Staley Mfg. Co., Decatur, Ill., *Chairman*

1. "The Analysis of Fillers in Paper by Spectrographic Methods," by Louis Block and John Lewis, Lowell Technological Institute, Lowell, Mass.

3:30 p.m. Patents (West Ball Room)

F. Makara, New York, N. Y., *Chairman*

1. "Patent Office Practice," by F. Makara, New York, N. Y.
2. "Recent Court Decisions," by F. Makara, New York, N. Y.
3. "Technical Manpower and Technical Information," by T. T. Collins, National Container Corp., Jacksonville, Fla.

THURSDAY, FEBRUARY 24, 1955

9:15 a.m. Alkaline Pulping (West Ball Room)

M. B. Pineo, Brunswick Pulp & Paper Co., Brunswick, Ga., *Chairman*

1. "An Investigation of the Accelerated Brightness Reversion of Bleached Slash Pine Kraft Pulp," by S. M. Rollinson, St. Marys Kraft Corp., St. Marys, Ga.
2. "The Use of Chemicals in Improving Southern Pine Timber Stands," by A. E. Griffiths, Ethyl Corp., New York, N. Y.
3. "Kraft Mill Odor Control," by J. Von Bergen, Airchem, Inc., New York, N. Y.
4. "Technical Data and Operating Figures from the Most Recent Kamyr Continuous Cooking Plants," by J. Richter, Kamyr, Inc., Hudson Falls, N. Y.

9:15 a.m. Plastics-Paper Combinations (South Room)

R. T. Nazzaro, Westfield River Paper Co., Russell, Mass., *Chairman*

1. "Properties of Latex Films Loaded with Inert Pigments," by E. B. Osborne, R. D. Savata, and G. J. Antifinger, B. F. Goodrich Chemical Co., Avon Lake, Ohio.
2. "New Developments in the Manufacture of Organic and Inorganic Synthetic Filter Paper," by H. F. Arledter, Hurlbut Paper Co., South Lee, Mass.
3. "A Motion Picture Investigation of Polymer Latex Phenomena," by J. W. Vanderhoff, Dow Chemical Co., Midland, Mich.
4. "Factors Influencing the Gas and Vapor Transmission of Polymer Films," by V. T. Stannett, New York State College of Forestry, Syracuse, N. Y.

9:15 a.m. Corrugated Containers Panel (Grand Ball-Room)

F. D. Long, Container Corp. of America, Chicago, Ill., *Moderator*

9:15 a.m. Packaging Materials Testing (Room A)

Howard S. Gardner, Fibreboard Products, Inc., Antioch, Calif., *Chairman*

Symposium—"Insect Resistance"

9:15 a.m. Microbiological (Room B-C)

B. F. Shema, W. H. & L. D. Betz Co., Philadelphia, Pa., *Chairman*

1. "Recent Developments in the Use of Chemical Treatments and Synthetic Fibers in Paper Machine Felts," by L. M. Woodside, Albany Felt Co., Albany, N. Y.
2. "Biological and Chemical Attack on Woolen Felts," by R. J. Purdy, Orr Felt and Blanket Co., Piqua, Ohio.
3. "Effect of Felt Design on Paper Machine Operation," by I. H. Peters, F. C. Huyck & Sons, Rensselaer, N. Y.

Technical Association of the Pulp & Paper Industry

Sixth Coating Conference

Statler Hotel, Cleveland, Ohio

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Sept. 19–21, 1955

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PERSONAL MENTION

Items About New and Old Tappimen

New TAPPI Members

Frederick A. Adams, Electrical Engineer, National Container Corp., Valdosta, Ga., a 1947 graduate of the University of Alabama.

John C. Baker, Sales Representative, Thompson Hayward Chemical Co., Minneapolis, Minn. Attended University of Missouri.

Edward D. Bast, Sales Engineer, Black-Clawson Co., Hamilton, Ohio, a 1946 graduate of Miami University.

Norman Beecher, Assistant Professor of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Mass., a 1948 graduate of Massachusetts Institute of Technology.

William B. Blackford, Apprentice Engineer, Halltown Paper Board Co., Halltown, W. Va. Attended Johns Hopkins University.

Charles B. Blanchard, Sales Engineer, Buffalo Rubber and Supply, Inc., Buffalo, N. Y.

Richard L. Bradford, Power Engineer and Chief Electrician, Mac Sim Bar Paper Co., Otsego, Mich.

John S. Brush, Converting Superintendent, Hudson Pulp and Paper Corp., Palatka, Fla., a 1929 graduate of Lake Forest College.

George W. Busby, Jr., Section Chief, Lever Bros. Co., Edgewater, N. J., a 1936 graduate of Worcester Polytechnic Institute.

Neil G. Clarke, Student, University of Maine, Orono, Me.

Ernest C. Cowell, Student, Western Michigan College, Kalamazoo, Mich., a 1951 graduate of the University of Michigan.

H. Lance Crosby, Process Development Engineer, Rayonier, Inc., Research Div., Shelton, Wash., a 1939 graduate of State College of Washington.

Donald R. Curtis, Engineer, Waldorf Paper Products Co., St. Paul, Minn., a 1949 graduate of the University of Colorado.

Winterton U. Day, Research Professional, Kimberly-Clark Corp., Neenah, Wis., a 1942 graduate of the University of Wisconsin with a Ph.D. degree.

Rodger C. Derby, Management Trainee, Champion Paper & Fibre Co., Hamilton, Ohio, a 1954 graduate of Harvard University.

Thomas A. Gardner, Paper Mill Engineer, Marathon Corp., Menasha, Wis., a 1949 graduate of Oregon State College.

Robert F. Ginn, Development Dept. of Ohio Boxboard Co., Rittman, Ohio, a 1953 graduate of Colorado University.

Floyd D. Gottwald, Jr., Production Manager, Albemarle Paper Mfg. Co., Richmond, Va., a 1951 graduate of the University of Richmond.

Keith M. Greenwood, Managing Director, Tragasol Products, Ltd., The Works, Hooton, Wirral, Cheshire, England.

Harold L. Gruehn, Sales Representative, Allis-Chalmers, Milwaukee, Wis. Attended the University of Wisconsin.

Charley Gustafsson, Assistant Director, Centrallaboratorium Ab, Helsingfors, Finland, a 1937 graduate of the University of Helsingfors with a Ph.D. degree.

Frederick H. Haney, Manager of Product Development, The Flintkote Co., Los Angeles, Calif., a 1932 graduate of Purdue University.

Christen G. Hansen, Chief Chemist, Noisk Wallboardfabrikk, Vikeland, Norway, a 1949 graduate of London University.

Adriaan Harsveldt, Chemist, Nationale Zetmeelindustrie N.V., Veendam, Holland, a graduate of Technical University, Delft, with a Ph.D. degree.

Donald E. Helleur, Technical Associate, Institute of Paper Chemistry, Appleton, Wis., a 1945 graduate of Queen's University.

G. Dewey Huston, Chemical Engineer, Puget Sound Pulp and Timber Co., Bellingham, Wash., a 1949 graduate of Kansas State College.

John F. Jahne, Chemist, St. Lawrence Paper Corp., Norfolk, N. Y., a 1953 graduate of Tri-State College.

Geoffrey E. Jowett, Sales Engineer, The Black-Clawson Co., Hamilton, Ohio.

Andrew B. Kearns, Sales Manager, Pioneer Paper Stock Co., Chicago, Ill.

Leland J. Kennedy, Engineering Assistant to the President, John Waldron Corp., New Brunswick, N. J., a 1933 graduate of Pennsylvania State College.

Paul E. Kiefer, Sales Development, Electrochemicals Dept., E. I. du Pont de Nemours & Co., Wilmington, Del., a 1950 graduate of the University of Southern California.

Joseph W. King, Supervisor of Paper Testers, Eastern Corp., Bangor, Me.

Clement J. Kusnierek, Resident Engineer, Minnesota and Ontario Paper Co., International Falls, Minn., a 1928 graduate of the University of Minnesota.

Freeman R. Lehman, Coatings Development Chemist, The Dow Chemical Co., Midland, Mich., a 1950 graduate of Michigan State College.

Hansjoachim Leugering, Chemist, Zellstofffabrik Waldhof, Mannheim, Germany, a graduate of Technical University with a Ph.D. degree.

Oma J. Lombard, Jr., Test Supervisor, Great Northern Paper Co., Millinocket, Me., a 1950 graduate of the University of Maine.

Charles N. Loveland, Jr., Project Engineer, S. D. Warren Co., Cumberland Mills, Me., a 1929 graduate of Yale University.

Paul J. MacCutcheon, Jr., Assistant to Vice-President, Production, Riegel Paper Corp., Milford, N. J., a 1939 graduate of School of Engineering, Columbia University.

Yoichiro Makita, Manager of Machinery Dept., Mitsubishi Heavy Industries Reorganized, Ltd., Tokyo, Japan, a 1925 graduate of Tokyo Imperial University.

Joseph Master, Research and Development Supervisor, Peter J. Schweitzer Co., Spotswood, N. J., a 1937 graduate of Brooklyn College.

Rex D. McDowell, Planning Section Chief, The A. L. Garber Co., Ashland, Ohio.

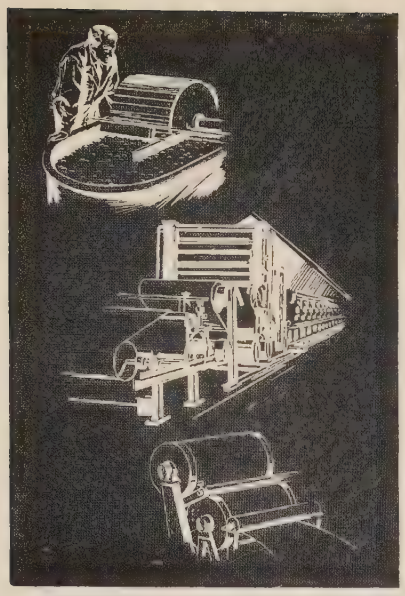
James F. McLaughlin, Vice-President in Charge of Manufacturing, Sherman Paper Products Corp., Newton Upper Falls, Mass. Attended Temple and Rutgers Universities.

Robert L. Mitchell, Chief Chemical Engineer, Celanese Corp. of America, Clarkwood, Tex., a 1947 graduate of Massachusetts Institute of Technology.

Daniel Newman, Sales Engineer, Stein, Hall & Co., Inc., New York, N. Y., a 1945 graduate of Rensselaer Polytechnic Institute.

James R. Patton, Sales Representative, Koppers Co., Inc., Chicago, Ill., a 1950 graduate of Grove City College.

Maximilian Pfluecke, Publisher and Editor, German Academy of Science, Berlin, Germany.



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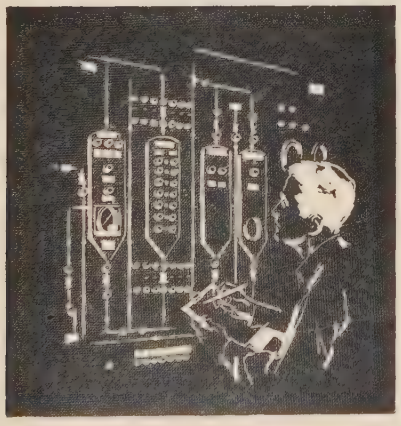

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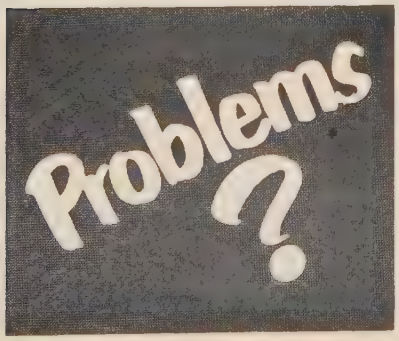

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Robert F. Plisch, Chief Chemist, Wausau Paper Mills Co., Brokaw, Wis. Attended University of Wisconsin.

Theodor Ploetz, Director and Chief Chemist, Feldmuhle Papier, Dusseldorf, Germany, graduate of Universitat Munchen with a Ph.D. degree.

Gerald P. Ritzema, Chemist, Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich., a 1947 graduate of Calvin University.

John M. Ruddell, Research and Development Chemist, Lee Paper Co., Vicksburg, Mich., a 1942 graduate of Indiana University.

Jean-Pierre Savary, Ingenieur, Pechiney, Paris, France, a 1938 graduate of Ecole Centrale.

Felix R. Schepman, Chief Chemist, N. V. Philips Gloeilampenfabrieken, Eindhoven, Holland, a 1946 graduate of Municipal University, Amsterdam, with a Ph.D. degree.

Benjamin Seibel, Group Leader, Fibrous Materials, Foster D. Snell, Inc., New York, N. Y., a 1933 graduate of the College of the City of New York.

Lawrence A. Shipman, Chemical Engineer, Marathon Corp., Menasha, Wis., a 1947 graduate of the University of Michigan.

Lars H. Sjodahl, Technical Supervisor, Gardner Board and Carton Co., Middletown, Ohio, a 1935 graduate of Massachusetts Institute of Technology.

Arvin J. Sorenson, Engineer, St. Regis Paper Co., Tacoma, Wash., a 1938 graduate of the University of Washington.

Walthur Stoetzer, Librarian, Farbfabriken Bayer, Leverkusen Germany, a 1928 graduate of the Technical University with a Ph.D. degree.

Frank J. Sullivan, Division Manager, Robert Gair Co., Cleveland, Ohio, a 1939 graduate of Syracuse University.

George R. Underwood, Bulk Sales Manager, The Hubinger Co., Keokuk, Iowa, attended Indiana University.

Michael Wales, Senior Research Chemist, Brown Co., Berlin, N. H., a 1948 graduate of the University of Wisconsin with a Ph.D. degree.

George F. Whiting, Secretary, Whiting Paper Co., Holyoke, Mass., a 1951 graduate of Amherst College.

Arne A. Wretne, Chemical Engineer, Aktiebolaget Statens Skogsindustrier, Djursholm, Sweden, a 1949 graduate of Stockholms Tekniska Institut.

Donald C. Young, Assistant General Manger, Whale Safety Paper Co., Waupaca, Wis., a 1935 graduate of Amherst College.

TAPPI Notes

Joseph Abelson has been discharged from the Army and is a Graduate Student at the New York State College of Forestry, Syracuse, N. Y.

O. A. Battista is now the Head of the Analytical Laboratories, Research & Development Div. of the American Viscose Corp., Marcus Hook, Pa.

Elliott R. Barker, formerly of Hollingsworth & Whitney Co., is now a Sulphite Mill Consultant, located in Whately, Mass.

Stanley W. Barrow, formerly of the Empire Paper Mills, Ltd., is now General Manager and Chief Papermaker for Albert E. Reed & Co., Ltd., Aylesford Paper Mills, Larkford, Kent, England.

Peter B. Borlew, formerly of the Container Corp. of America, is now Technical Superintendent of the National Container Corp., Jacksonville, Fla.

Richard J. Bouchard, formerly of the Whale Safety Paper Co., is now Night Superintendent of the Gilman Paper Co., Gilman, Vt.

N. William Coster is now Pulp Mill Manager of the Soundview Pulp Div., Scott Paper Co., Everett, Wash.

Wayne G. Davis is now Vice-President in Charge of Felt Sales for the Albany Felt Co., Albany, N. Y.

Foster P. Doane is now Vice-President of the Bergstrom Paper Co., Neenah, Wis.

Richard L. Elderkin, formerly of the Abitibi Power & Paper Co., Ltd., is now an Engineer at the Wayagamack Div. of Consolidated Paper Corp., Ltd., Three Rivers, Que.

J. A. Extrom, formerly of the Alton Box Board Co., is now General Manager of the Chase Bag Co., Chagrin Falls, Ohio.

A. J. Felton of Shartle Bros. Machine Co. has been transferred from Fulton, N. Y., to Middletown, Ohio, as an Executive Sales Engineer.

George E. Field is now General Manager of the Plastics Products Div., B. F. Goodrich Chemical Co., Marietta, Ohio.

Thomas E. Flanagan, Chemist for the Kalamazoo Vegetable Parchment Co., has been transferred to the KVP of Canada, Ltd., Espanola, Ont.

Raymond A. Greene, Sales Representative for the Merrimac Div., Monsanto Chemical Co., has been transferred to the Organic Chemical Div. in New York City.

Carl Hackbarth, formerly of Sociedad Agricola Paramonga (W. R. Grace & Co.), is now Paper Mill Superintendent for the North Carolina Pulp Co., Plymouth, N. C.

G. Emil Haeger, formerly of Inlands A/B, is now General Manager of Fridafors Fabriks A/B, Fridafors, Sweden.

Herbert R. Helbig of Reichhold Chemicals, Inc., has been transferred from Charlotte, N. C., to White Plains, N. Y., as Production Sales Manager.

Charles J. Higgins, formerly a student at the Lowell Technological Institute, is now in the Control Methods Dept. of the Dixie Cup Co., Easton, Pa.

Robert S. Ives, Consultant, has removed his office from Belmont, Mass., to 28 Birch St., Cambridge 38, Mass.

Mrs. G. A. Edw. Kohler, Secretary of the Kohler System Co., died on October 9. Her husband, who died in 1932, was noted for the development of the magazine reel and the electric drive for printing presses. She is survived by two sons, John B. Kohler and Frank Kohler.

Elliott S. Kohn, Engineer for Rowland Tomkins & Son, Inc., has transferred his office from New York City to Hawthorne, N. Y.

Thomas M. Lalor, formerly of the Champion Paper & Fibre Co., is now Technical Director of the St. Marys Kraft Corp., St. Marys, Ga.

Robert L. Leaf, Jr. is now Vice-President in charge of development of the Shawano Paper Mills, Shawano, Wis.

Fritz A. Maier, formerly of the West Virginia Pulp & Paper Co., is now in the Army Quartermaster School, Fort Lee, Va.

Stephen Malinauskas, formerly of the American Sugar Refinery, is now Assistant Production Manager of the Merrimac Paper Co., Inc., Lawrence, Mass.

Cyril H. Marsh is now Deputy Research Liaison Officer of the Metal Box Co. Overseas, Ltd., Acton, London, England.

Harold R. Murdock, Consultant, is now located at 2025 Peachtree Rd., Atlanta, Ga.

Robert V. Parkinson of the Research Dept., Spencer Chemical Co., has been transferred from Kansas City to Pittsburg, Kan.

Etienne Perrigot is now Director General Adjoint of Papeteries Arches Johannot Marais, Paris, France.

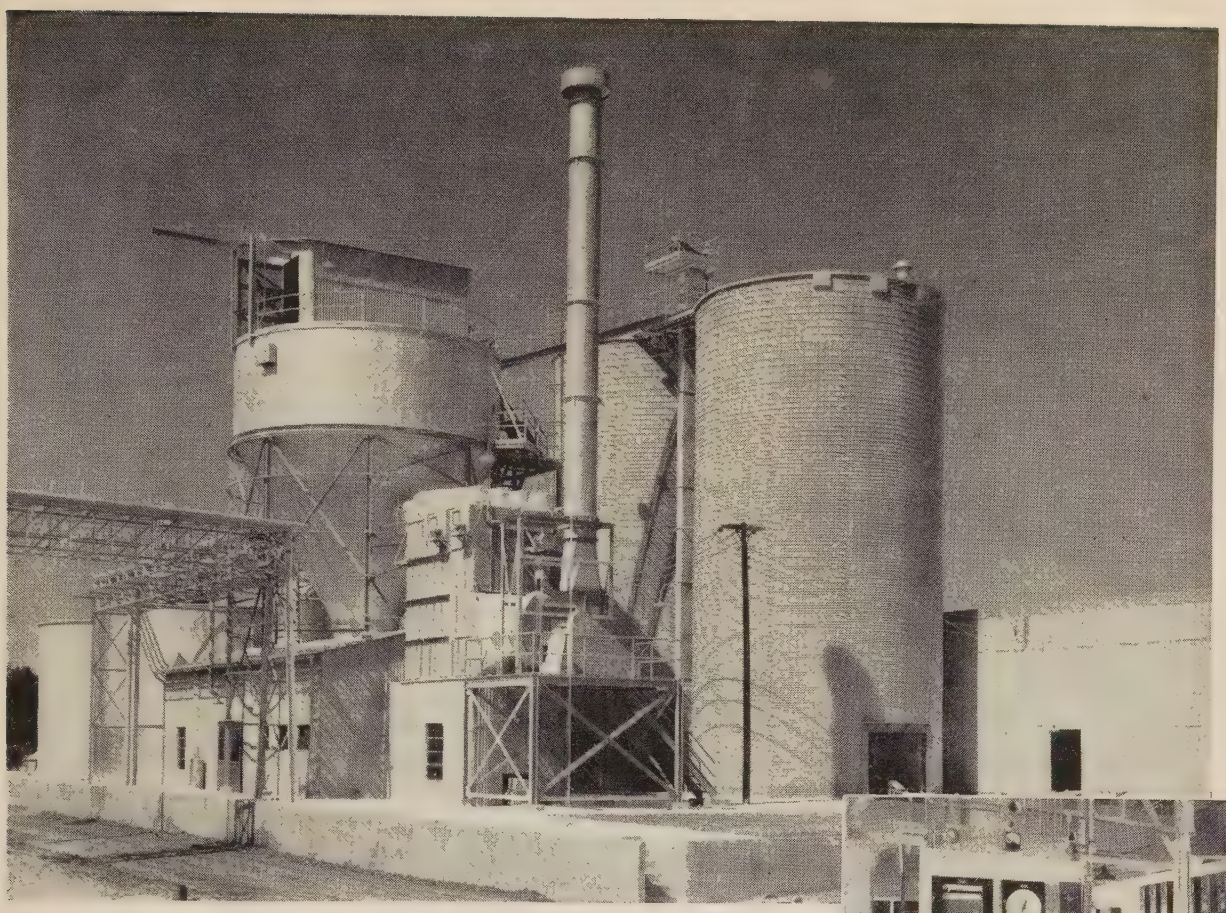
Walter L. Perro is now Pulp Mill Superintendent of the Chicasaw Mills, Hollingsworth & Whitney Co., Mobile, Ala.

Freeman Perry, formerly of the Chemical Paper Mfg. Co., is now Production Manager of Ward Paper Co., Merrill, Wis.

Charles L. Pinat is now Director General of Papeteries Arches Johannot Marais, Paris, France.

John A. Pietrowski, formerly of the Raritan Arsenal, is now a member of the technical staff of Paterson Parchment Paper Co., Bristol, Pa.

Joseph Rossman, Patent Attorney for the Marathon Corp., has removed his office from Philadelphia to 1820 Jefferson Place, N. W., Washington 6, D. C.



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Frederick B. Schelhorn of the National Container Corp. has been transferred from Valdosta, Ga., to Jacksonville, Fla., as Plant Manager of the Mill Div.

Ronald Schutts, formerly a Student at the New York State College of Forestry, is now a Production Trainee of the Armstrong Cork Co., Pensacola, Fla.

Sigurd Solvason, Project Manager of Merritt, Chapman & Scott Corp., has been transferred from New York City to Klamath Falls, Ore.

J. G. Sylvester, formerly with the Mutual Boiler and Machinery Insurance Co., is now a member of the firm of J. G. Sylvester Associates, 44 Clarendon St., South Weymouth, Mass., consulting specialists in industrial radiography.

Breckenridge K. Tremaine, formerly of du Pont, is now Technical Director of the Industrial Deodorant "Alamask" Div. of Rhodia, Inc., New York, N. Y.

H. Dale Turner, Chemical Engineer for the Olin Mathieson Corp., has been transferred from East Alton, Ill, to New Haven, Conn.

Frederick M. Viles, formerly of Brakely & Dexter Laboratories, is now an Engineer for the Ultrasonic Corp., Cambridge, Mass.

William A. White, Jr. is now General Manager of the Bagley & Sewall Corp. Div. and Vice-President of the Black-Clawson Co., Watertown, N. Y.

Dan B. Wicker, formerly of the American Cyanamid Co., is now Assistant Director in Charge of Physical Research for F. C. Huyck & Sons, Rensselaer, N. Y.

James H. Wing, formerly of the American Optical Co., is now in the Research Dept. of Robert Gair Co., Uncasville, Conn.

Robert Worden is now a Research Chemist in the paper pilot plant of the Minnesota Mining & Mfg. Co., St. Paul, Minn.

Donald E. Yost, formerly of the Combined Locks Paper Co., is now Engineer for the Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich.

* * *

G. W. Seymour, official representative of the Celanese Corp. of America in the Technical Association, has removed his office from New York City to Charlotte, N. C.

Papeteries d'Arches and Papeteries du Marais, Paris, France, have been merged to form Papeteries Arches Johannot Marais.

The address of Rogers Corp. has been changed from Manchester, Conn., to Rogers, Conn.

The name of the Institute of Food Technology, Munich, Bavaria, Germany, has been changed to Institute of Food Technology and Packaging.

Members of the first full graduating class from the paper department of the Lowell Technological Institute are now located as follows:

Kenneth B. Hallas, Dixie Cup Corp., Easton, Pa.
Charles J. Higgins, Dixie Cup Corp., Easton, Pa.
Albert J. Marchand, Fraser Paper, Ltd., Madawaska, Me.
Robert J. Pellicione, International Paper Co., North Tonawanda, N. Y.
Warren S. Rushton, McLaurin-Jones Co., Brookfield, Mass.
Edwin Zale, Sealright Corp., Fulton, N. Y.
Arthur Tournas, Graduate Student, University of Maine, Orono, Me.

The name of the Forest Products Laboratory Dept. of Resources and Developments, has been changed to the Dept. of Northern Affairs and National Resources at Vancouver, B. C., and Ottawa, Ont.

To correct some confusion caused by earlier reports, K. G. Aitken of Canadian Industries, Ltd. advised that *H. H. Hubel* and *D. E. Read* are still with Canadian Industries, Ltd. in Montreal. *A. J. Cameron* and *F. M. Languedoc* are now with du Pont Co. of Canada, Ltd. *W. J. Loney* is now with Western Chemicals, Ltd. at Duvernay, Alberta.

* * *

John R. Dufford, Assistant General Manager, has succeeded *R. T. Anderson* (deceased) as the official corporate representative of the Paterson Parchment Paper Co., Bristol, Pa., in the Technical Association.

Industry Notes

Production

Paper and board production during August amounted to 2,289,744 tons, according to the Bureau of the Census, Depart of Commerce. This is 1% below the 2,311,760 tons produced in August a year ago. Paper production amounted to 990,916 tons, almost 3% above the 962,111 tons produced in August a year ago. The output of paperboard was 1,030,383 tons, reflecting a 6% decrease from the production of 1,098,152 tons reported during August, 1953.

Pulpwood receipts at the pulp mills during August amounted to 2,512,755 cords, with consumption at 2,527,748 cords.

Receipts of fibrous materials other than wood pulp, totaled 761,407 tons. Consumption at 803,439 tons was more than receipts, and inventories of 863,309 tons at month's end reflected a 5% decrease. Receipts of waste paper at 672,202 tons were also less than consumption which amounted to 696,506 tons. End of month inventories of waste paper at the mills, accordingly, showed a 5% decrease to 440,903 tons.

Wood pulp production during August amounted to 1,571,940 tons as compared to 1,530,491 tons produced in August a year ago.

Production and shipments of newsprint in North America during September, 1954, amounted to 587,745 tons and to 580,761 tons, respectively, compared with corresponding totals of 553,397 tons and 568,422 tons in the same month of 1953. North American production in September, 1954, exceeded that in any previous September. Output in the United States was 96,592 tons and shipments were 98,202 tons while Canadian (including Newfoundland) production amounted to 491,153 tons—the peak September record to date—and shipments totaled 482,559 tons.

Through the end of September this year United States mills turned out 53,248 tons or 6.6% more newsprint than in the first nine months of 1953 while output in Canada also was 171,960 tons or 4.0% greater than in the corresponding period of last year, thus the total continental increase amounted to 225,208 tons or 4.4%.

China

A recent Peking report that China is moving towards self-sufficiency in paper supply throws some interesting light on the progress that has been made during the past few years to revive an industry that had reached a very low ebb when the present Chinese government took office at the end of 1949. Although in the past China, in relation to her size, was not important in the world paper trade, indications are that she is likely to constitute a more significant factor in the future. Already she is a useful buyer of paper from some of the east European countries and—more noteworthy, perhaps—she has begun exporting certain types of paper to some of her southeast Asian neighbors.

Expanding Domestic Production

By the end of 1952 China's paper output exceeded the highest previous annual figure and this year, for the first time, paper for educational uses has been produced in sufficient quantity to meet the home demand. A growing proportion of the paper used in the country's expanding industry is also now being manufactured by Chinese mills.

Anaconda First to Roast Low Grade Sulfur Ore to produce SO_2 for Acid Manufacture

The world's first commercial installation for producing SO_2 gas from low grade sulfur ore, is now on stream at Anaconda Copper Company's plant at Weed Heights, Nevada.

The FluoSolids System that makes this possible includes four 18 ft. dia. Reactors plus other Dorr and auxiliary equipment. SO_2 gas is sent to a 450 TPD contact acid plant which supplies all acid requirements for leaching 11,000 tons of copper ore per day.

Feed to the system is 650 to 750 tons per day and gas production 26,000 to 30,000 C.F.M. Gas strength averages 8 to 12% representing a sulfur recovery of 98%. Unusual? Yes, because this is the first time that low grade sulfur ore could be recovered as SO_2 . . . economically. Here's how the system works . . . ore averaging 28% total sulfur is crushed to 10 mesh and fed dry to the Reactors which operate in parallel. Once ignition temperature is reached no extraneous fuel is needed. Ore is simply fed in at the design rate, latent heat in the bed immediately brings it to ignition temperature, and the fluidizing air oxidizes the sulfur to SO_2. Shutting down is a matter of minutes. And because the fluid bed stores sufficient heat, roasting can be started again after as much as 72 hours without adding additional fuel.

If you would like more information of FluoSolids . . . the most significant advance in roasting technique in the last 30 years . . . write The Dorr Company, Stamford, Conn., or *in Canada*, The Dorr Company, 26 St. Clair Avenue, East, Toronto 5.

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It was, of course, a Chinese, Tsai Lun, who is credited with the invention of paper over 1800 years ago during the Han Dynasty—more than a thousand years before its first appearance in Europe. Through the centuries the country has been famous for its handmade papers and these are still turned out by individual handicraft workers and cooperatives. For many years, however, China was dependent on imports for most of the paper used for educational and cultural purposes and for all the paper in industrial use. During the second World War, for instance, production of machine-made paper in the provinces not occupied by Japan totaled no more than about 260,000 reams, of which more than one half came from Szechwan. At that time there was one government-operated mill, the Central Paper Mill, reorganized from the Lung Chang paper mill, Shanghai. Large private mills included the Chung Yuan, Kien Kuo, Kia Lo, Cheng Chung, and Tungliang paper mills, producing printing paper, newsprint, wrapping, and cigarette paper.

The first modern paper mills were set up in China at the end of the last century but never developed. They remained poorly equipped and technically backward and had to import machinery—as well as pulp—from the United States, Japan, and Britain. Although over 90% of the population was illiterate and the *per capita* annual consumption of paper was less than1 lb., even this small demand could not be met by home industry and the bulk of the machine-made paper used in the country was imported. During the war against Japan when imports of foreign paper were cut off, most Chinese newspapers, magazines, and books were printed on handmade paper, the production of which experienced a certain revival. Imports were resumed after the war, however, and China's national industry proved unable to compete with foreign papers.

Rehabilitation After Civil War

The result was that by the time the civil war ended on the mainland, most of China's few paper mills were out of operation. Initially government action to revive the industry took the form of improvement and expansion of production in the existing mills. Among the important plants affected by this program were state mills in Tientsin (originally built by the Japanese in 1939), Kirin (Manchuria), and Canton. In 1952, the Chinese press has reported, the Tientsin mill produced more than three times the annual average of the years of Japanese occupation. The Kirin mill was re-equipped, increasing its daily production from 20 to 150 tons. The Canton mill, stripped of all its machinery by the Japanese, began producing newsprint again at the beginning of 1951. It has since been reported that machines at the mill are working at more than 40% above their rated capacity.

Rehabilitation measures undertaken by the Chinese Ministry of Light Industry were also applied to privately owned paper mills. A number of new ones have also come into operation in recent years, including two in Shanghai. Among private mills one of the most spectacular revivals has been that of the Kongmoon mill in Kwangtung Province which last year exceeded its best prewar output.

Output Trebled

The output of machine-made paper in China last year was nearly three times the 1950 production. The manufacture of newsprint has trebled and today practically all the newsprint used throughout the country is home produced. Shanghai, for instance, is now said to be manufacturing four times as much paper as in 1950 and, according to the Chinese press, last year produced enough newsprint "to turn out 370 million copies of newspapers." This important center of Chinese light industry is also now producing high-quality bond and drawing paper in large quantities. Both were formerly imported.

Increasing the range of its products has in fact been one of the most notable successes of the Chinese industry. The country's paper mills now produce more than 100 kinds of paper for diverse industrial uses ranging from cigarettes to cement bags, as well as sensitized paper, insulating paper, and drawing paper. To meet industrial needs, trial production is beginning this year of certain new kinds of industrial paper including fiber sheets and paper used in aeronautics, car manufacture (the first Chinese automobile plant is now under construction in Manchuria), and building work. The different varieties of paper being produced at the present time meet most of China's own needs, with the exception of certain types of industrial paper and some high-quality items like superfine bond and art paper which are not at present in great demand. Imports include limited quantities of newsprint, writing and typing paper, kraft paper and cardboard. Cigarette paper and banknote paper, always imported in the past, are now fully supplied by Chinese mills.

Machine-Made Exceeds Hand-Made

One result of this increased range and output is that for the first time in the country's history the volume of machine-made paper produced in China exceeds that of hand-made paper. China's handicrafts have traditionally played an important part in the national economy and continue to do so. Something like 70% of current production in the field of light industry is still on a handicraft basis. Paper plays a big part in handicraft production and until very recently 50% of the paper produced in China was handicraft-produced. Present government policy is to encourage handicraftsmen to join handicraft producers' cooperatives and some indication of the scale on which this is taking place can be gained from the fact that in 1953 handicraft co-ops produced 30,000 tons of paper pulp.

In the past few years 12 paper mills have been reconstructed in China and a number of new up-to-date mills built. Extensions and new projects now under way are expected to raise the capacity of the state-owned paper industry by more than 50%. Extensions to the big Kwangtung paper mill (Canton) completed earlier this year will make possible a 60% increase in newsprint output compared with 1953. These extensions are described as only the first stage in plans to make the big state-owned mill one of China's major newsprint suppliers. Work so far done includes the installation of new grinders for making mechanical pulp and digesters for chemical plup. In the past, both mechanical and chemical pulp required by the mill came from other mills. When the expansion program is completed in 1956 the mill will have a capacity five times as big as in 1953 and will turn out more than 10,000 tons of chemical wood pulp a year for other paper mills.

Of the new paper mills currently being built by the government, the largest is at Kiamusze, in northeast China (Manchuria). It was begun in June, 1953, and will be finished by 1957. Its plant will include a pulp mill for the large-scale production of sulphate wood pulp. Among its products will be industrial papers, kraft bag papers, and electrical insulating papers. The raw material will come from the extensive neighboring forests and the coal from the nearby Hokang mines. It will have the most up-to-date Soviet machinery, with an efficiency, according to Hsu Ho-kuei, who is in charge of paper production in China's Ministry of Light Industry, "three to five times that of the best machines working in China at the present time." The number of workers required will be a third of that needed in an old-type mill of similar capacity.

Domestic Machinery Production

In the main, however, China's paper industry no longer depends on imported equipment, and domestic production of modern papermaking machinery has been officially hailed as one of the most favorable omens for the further development of the Chinese industry. Grinders, digesters, filters, bleach-

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ing tanks, and other machinery are already being made in Manchuria, Tientsin, and Shanghai. Two big new paper mills in Kiangsi and Hupeh Provinces—the latter in Wuhan (Hankow)—are equipped entirely with machines made in China. Another mill completed early this year along the Huai River in Anhwei Province was designed by Chinese engineers and most of the equipment and machines were made in China. The mill's chief raw material, incidentally, is hemp, available in abundance in the locality.

By far the most difficult problem the Chinese have had to overcome in developing their industry has been that of pulp. Previously, the paper industry depended on imported pulp and equipment in the factories was adapted to the use of foreign varieties only. Though wood pulp was produced on a large scale in Manchuria during the Japanese occupation, most of it was shipped to Japan for the rayon industry. The small beginnings of a pulp industry that sprang up in west China did not last after the defeat of Japan. Because the bulk of China's timber output is needed for other purposes, such as building, the paper industry was forced to find substitutes. During the past three or four years, with the assistance of Soviet experts, much has been done in this direction. Pulp is now made from rice-straw, bamboo and sugar-cane residue, all of which China has in abundance.

Soviet Pulping Techniques

A Soviet expert, N. Z. Verechitin, was largely responsible for working out the necessary mass-production techniques, which did not exist in the past. He applied the latest theories of fiber disintegration in his research, and his first success was the production of a semichemical rice-straw pulp. It went into large scale production in a Peking mill in the Spring of 1952 and is now being produced all over the country. Chief advantages claimed for the pulp are its high production rate, the small percentage of chemicals needed, improved tensile strength, and the short time and simple equipment needed for its preparation. The new pulp is said to have increased the production of paper and lowered its cost. Mr. Hsu has described it as "an important forward step in the history of the paper industry of China."

Verechitin also visted southwest China where he helped to solve similar problems with bamboo and sugarcane residue. Up to that time sugarcane residue had only been used for the making of cardboard, it having been held by most experts that in order to make fine paper the pith which constitutes 50% of the residue must first be removed. The Soviet expert set out to disprove the idea and claims to have succeeded in producing an inexpensive paper of high quality without discarding the pith. Paper made entirely of sugarcane residue pulp is now in wide use in China. Verechitin's experiments in the making of pulp from bamboo have resulted in what is described as "an entirely new kind of newsprint, consisting of a mixture of mechanically prepared bamboo pulp with 40% of wood pulp."

With a population of some 600 million (of whom about 580 million live on the mainland) and an intensive drive to spread literacy even to the most remote village, China is at the present time an enormous consumer of paper for educational and cultural needs. Some figures from the Chinese press are impressive: for the 1954–55 school year more than 180 million textbooks were published for middle and primary schools; altogether this year over 330 million textbooks have been issued, and this does not include publications in Mongolian, Korean, Uighur, Tibetan, and other minority languages; this year 2 million-odd copies of books on physical culture and sports are being published; the biggest publisher of children's books in China is turning out about 5 million books a year.

Under current trade agreements China is exporting paper to Burma, Viet Nam, and Indonesia (newsprint, miscellaneous paper, paper joss). Imports are coming from at least two of China's eastern trading partners, Czechoslovakia and Poland. It is interesting to note, too, that when China's vice-Minister of Foreign Trade, Lei Jen-min, visited Finland in August he said, after inspecting large paper mills, shipyards, and metal plants, that what he had seen had convinced him that "there are wide prospects of trade between China and Finland."

—from *The World's Paper Trade Review*, Oct. 7, 1954.

Africa

A pulp and paper mill, to produce 2000 tons of newsprint and 12,000 tons of pulp annually from bagasse, is under construction at Luanda, Portuguese Africa.

Sweden

In spite of the pronounced seller's market, wood pulp prices have remained more or less unchanged. The Swedish exporters have generally quoted the same prices for the fourth quarter as for the two previous quarters. Only in a few cases have there been minor upward adjustments. Two factors contributing to this stability have been the increased American offerings of pulp on export markets and the lower price level on the American domestic market. It is, however, also evident that the exporters have sought to avoid a repetition of the sharp price fluctuations that occurred in 1951–52.

Alabama

A report on Alabama's forest industry has been issued as Forest Survey Release 74 by the U. S. Forest Service's Southern Forest Experiment Station, 2026 St. Charles Ave., New Orleans, La.

Northern New York

When papermakers from northern New York get together conversation invariably gets to the movement of the paper industry away from this New York area. Just to see what there is to this tale we decided to take a trip by car and road map over the highway following the Black River. Historians would have found the trip more to their liking than we did. It was a nice trip if one is looking for ruins of buildings because ruins are what we saw the most of.

The real part of the trip began at Carthage, N. Y., and from there to Dexter, N. Y., it was one ruin after the other. All reminders of what the paper industry meant to northern New Yorkers in the past. The Black River must have been a busy pulp and paper producing river at one time. It still is—in spots, but not every few miles as it used to be.

At Carthage we passed the Island Paper Co., now only buildings. At Great Bend only ruins stand along the river bank to remind us of a mill that once was part of the Sherman Paper Co. Driving along a new road between Great Bend and Felts Mills we remembered an old smoke stack that stood along the river with the letters LeFebvre printed on it. The stack has disappeared now and very little remains of the LeFebvre pulp mill that was such a busy place years ago.

It's only two miles from Great Bend to Felts Mills and it didn't take us too long to pass what is left of another Sherman Paper Co. mill that formerly offered employment to residents of Felts Mills. Next stop was Black River where two more companies, once very active, had deserted their mills to the effects of time and weather. The Remington Pulp Mill and the Herring Paper Co. are now nothing. Watertown was once the city around a mill owned by the International Paper Co. but now only electric power is made there by Niagara Mohawk Power Corp. Black-Clawson, formerly the Bagley and Sewall Co., builds papermaking machines and equipment where once stood a paper mill owned by Hinde and Dauche.

Between Watertown and Dexter, N. Y., the average is one ex-mill every mile. Quite startling! At Glen Park, International Paper Co. had three mills; Brownville was the home of the Harman Paper Co. and in Dexter stands what is left of the old Frontinac Co. and Dexter Pulp and Paper Co. Altogether in the short span of 26 miles we counted 14 pulp and

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paper mills no longer in existence. We did not mention the mill at Port Leyden, N. Y., formerly Kelly Forsythe, that just recently closed its doors and went out of business. Fifteen Black River mills no longer in business when at one time there were 25 mills turning out pulp and paper products. Simple mathematics will tell you that this amounts to a 60% death record.

Returning to our own mill we took out our road map and looked around the north country. Pyrites on the Grass River and Raymondville on the Racquette were big mills in their day and old timers in the area will easily recall these two paper mills. They are gone now too—both mills a reminder of what was once.

But our story does not end yet. The Oswegotchie River also has a few dead mills lining its banks. Emeryville and South Edwards had mills but gave them up. Most recently another close neighbor of ours, Harrisville, closed its doors on papermaking; we all still have hopes that this mill will reopen. Long ago there were several pulp mills, whose names we do not know, strung along the Racquette River. These are now hydroelectric plants.

It is true then that there is a movement away from the north, and the Black River in particular. The record speaks for itself and brings home the very important point that we must produce a quality sheet of paper and operate at low cost to enable our mill to compete with bigger and more modern low cost mills. Only this way can we assure ourselves that this company will not be the 16th mill to abandon its pulp and paper business along the Black River.

—From *Plant Echoes*, published by employees of Gould Paper Co., Lyon Falls, N. Y.

UN-FAO Meeting

Latin-American pulp and paper experts held a two-week session in Buenos Aires in October to consider a new UN-FAO survey which indicated that underdeveloped countries will nearly double their paper consumption in the next eight years.

The meeting was held under the auspices of the Food and Agriculture Organization, the UN Economic Commission for Latin America, and the UN Technical Assistance Administration.

The experts had before them a new FAO forestry survey, "World Pulp and Paper Resources and Prospects," as a basic document for discussion.

The survey, which was prepared by FAO in cooperation with UNESCO and the UN Economic Commissions for Europe and for Latin America, points out that world paper consumption, which averaged 47 million tons annually during 1950–52, is estimated to rise to 65 million tons annually by 1960–62. About 13 million tons of this increase will take place in Europe and North America. The survey noted that while these areas will increase production they are not expected to have an appreciable surplus available for other areas. The less-developed areas will thus have to seek new sources for the expected increased consumption in their own areas. They now consume about 4.5 million tons of paper annually. Their requirements are expected to rise by another 4 million tons annually by 1960–62.

New York Forests

The Northeastern Forest Experiment Station, Upper Darby, Pa., has published Forest Statistics for New York Forest Districts Nos, 7, 8, 9, and 10. The station's *Forest Research Notes* gives data on the relationship of stump diameter to d.b.h. for white pine in the northeast.

Forest Genetics

The science of genetics is an increasingly important ally of forestry. The United States Forest Service is greatly expanding its work in this field, started with limited funds 20 years ago. Other agencies, such as associations of foresters,

wood producers and users and universities are conducting successful field and laboratory research on the development of better forest trees.

Selection is one way of improving tree stock; about three fourths of commercial United States woodlands are regenerated naturally from seed trees left standing. By selecting the most desirable trees for seed, or leaving blocks of vigorous or otherwise desirable trees when complete cutting is necessary and by culling least desirable trees when thinning the second growth, the quality of the stand may gradually be improved.

When planting is necessary, nursery stock from selected seed trees is desirable. State nurseries and those operated by owners of large forest areas are concentrating increasingly on producing high quality seed from known sources. Although this is an important and valuable initial step, improvement is limited to the best of the wild trees.

Tree breeding, while more expensive and time-consuming than selection, permits creating entirely new combinations of genes; some of the trees thus produced may be superior to the naturally occurring types. Work to date indicates that disease-resistant trees, or those with high yield or other special characteristics may be bred to order, as has been done for corn and other crop plants. Hybrids are produced by control of pollination, accomplished through bagging the female flowers of a superior tree and introducing pollen from another desirable tree into the bag. The hybrid offspring often inherit and may benefit from the desirable characteristics of both parents. Superior trees, either found in the wild or produced through breeding, may be propagated by vegetative techniques, such as grafting, budding, or rooting. The "offspring" are then genetically identical with the superior parent.

The Institute of Forest Genetics in California has produced nearly 80 hybrid types of pine. Some of these show great resistance to bark beetles and the pine blister rust; others have large-diameter stems, and fewer, smaller branches than the parent trees. Similar work on poplars has produced vigorous trees, resistant to many diseases and adapted to a harsh climate.

Sustained Yields. There are now only about 700,000 square miles of commercial land suitable for growing timber in the United States, but if all this land were fully stocked, it could supply the total United States demand for forest products. About 49,000 square miles are devoted to tree farming, where the forest tract is managed in accordance with high standards of forestry, with protection from fire, insects, and other destructive agencies, and provision for either natural or

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artificial regeneration, for permanent and continuous timber production. Second crops, however, may require 30 to 100 years to develop, depending on the species and the end use, before they are ready for harvesting. About 111,000 square miles are denuded or poorly stocked, and will probably require planting to bring them back to productive condition. For such areas, the genetically improved planting stock supplied by the tree breeder may be expected to increase markedly the quality and yield of the raw materials produced.

Tall Oil

A recent estimate shows that a quarter of all the whole (crude) tall oil and half of all the refined tall oils made in the United States end up as surface coatings, core oils, linoleum, and other resin products.

These important end uses for tall oil have been growing for years and producers continue to add capacity to meet projected increases in demand. Improvements in the quality of all grades of tall oil have been considerable during the last several years and tall oil producers may be expected to meet more and more of the special requirements of resin manufacturers.

The increasing use of tall oil in resins has been aided not only by the continued low cost of tall oil and steady, abundant supplies, but also by remarkable advances made in the chemical industry. Many new chemicals are appearing—polyols, modifiers, and other resin chemicals—that make tall oil more and more useful to resin manufacturers. Some of the many applications for tall oil in the resin industry were reviewed in our previous Bulletin 13. The numerous references cited there are proof of the active interest in using tall oil for commercially important resins. The present Bulletin demonstrates that manufacturers of more complex resins like alkyds, noting the low cost and reliable grades of tall oil available, are also increasing their use of this versatile raw material.

Alkyd Resins

Alkyd resins are important constituents in protective coatings. In 1953 production was about 370 million pounds for the 1.4 billion dollar paint industry. Tall oil is widely used in the manufacture of such alkyd resins.

Alkyd resins is the name chemists have for the resins made by esterifying polyalcohols with polycarboxylic acids. The word alkyd is intended to suggest this, sounding like the first three letters of *alc(ohol)* and the last two of *(ac)id.*

With the many polyols and polyacids available today an almost countless number of combinations could be made and hundreds have been investigated. However, cost limitations permit relatively few to become practical. Alkyds are generally classified by the principal polyacid used. Thus phthalic acid, usually used in the form of phthalic anhydride is the basis of *phthalic alkyds.* Maleic acid, usually used in the form of maleic anhydride, is the basis of *maleic alkyds.* Fumaric acid, the isomer of maleic, is often grouped with maleic. The many other polyacid alkyds, as well as maleic, when used only in minor proportions with phthalic are termed modifiers and are generally grouped with phthalic.

Any classification of the many alkyds is inadequate for a general view of the properties and uses of alkyds; there are too many aspects to consider. Thus, the acids used may be saturated or unsaturated, long chain or short chain, dicarboxylic or tricarboxylic, monomers or polymers. Each kind affects the properties of the product. The many kinds of polyalcohols used likewise contribute special properties to the product.

In addition to such kinds of pure alkyds there is an increasing tonnage of alkyds copolymerized or otherwise modified with other resins.

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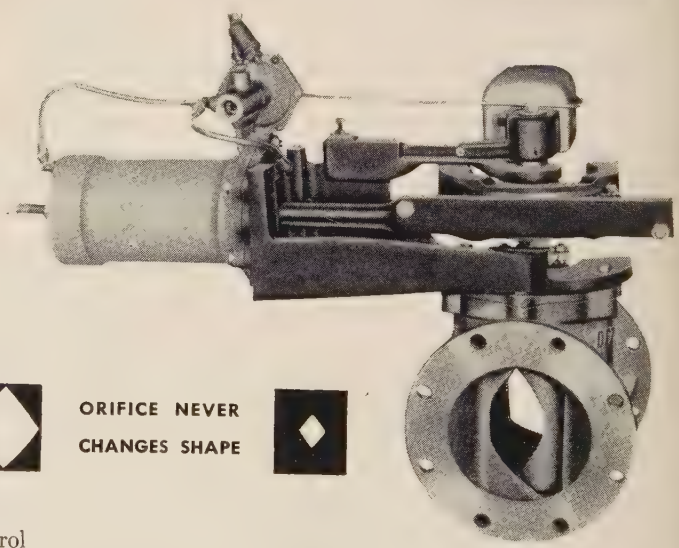

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Tall Oil in Alkyds

A large portion of the alkyds used in protective coatings is modified with drying oils or unsaturated fatty acid esters. Many are also modified with rosin esters. A large amount of tall oil goes into such modified alkyds.

The pure alkyd is typically a hard brittle resin, not sufficiently soluble in solvents, nor sufficiently compatible with other vehicles. Its value as a coating is greatly enhanced by modifications, such as with tall oil. The product is flexible, tough, and hard, rather than brittle, and is quite soluble in low cost solvents and compatible with most other varnishes. The fatty acids of tall oil are relatively free of the highly unsaturated fatty acids like linolenic which cause yellowing, on aging. In addition, the low cost of tall oil reduces the over-all cost of the product.

Rosin is also used extensively and tall oils of widely varying rosin acids content, from negligible amounts—less than 1%—to as much as 50%, are available to cover the diverse needs of resin manufacturers.

Oil modified alkyds are classed as short, medium, or long, depending on the oil to resin ratio. This ratio is expressed in the trade as gallons oil length and is computed as the gallons of pure fatty acid esters per 100 lb. of resins. The resins include the esters of all polyacids, rosin acids, as well as any phenolic or other resins present.

While these terms are analogous to those used for oleo-resinous varnishes, the values differ somewhat for each:

	Oil length, gal.		
	Short	*Medium*	*Long*
Alkyds	9–12.5	14–20	22–29
Oleoresins	6–15	20–30	35–60

Oil modified alkyds are also classed by their per cent of a polyacid or by their per cent of oil and many are coming to prefer such a more specific numerical designation.

The usefulness of tall oil modified alkyds will probably be extended in the near future as chemists restudy their older results with the new higher grades of tall oil that have become available. Already, tall oil modified alkyds are widely used for coatings suitable for metal and wood enamels, primers, and one coat nonpenetrating flat paints. Such applications are to be seen everywhere on railroad cars, farm implements, houses, barns, toys, hardware, furniture, and many other everyday products.

References: 1, 2, 3, 10, 18, 27, 28, 29, 30, 33, 37, 43, 45, 47, 48, 51.

Phthalic Alkyds

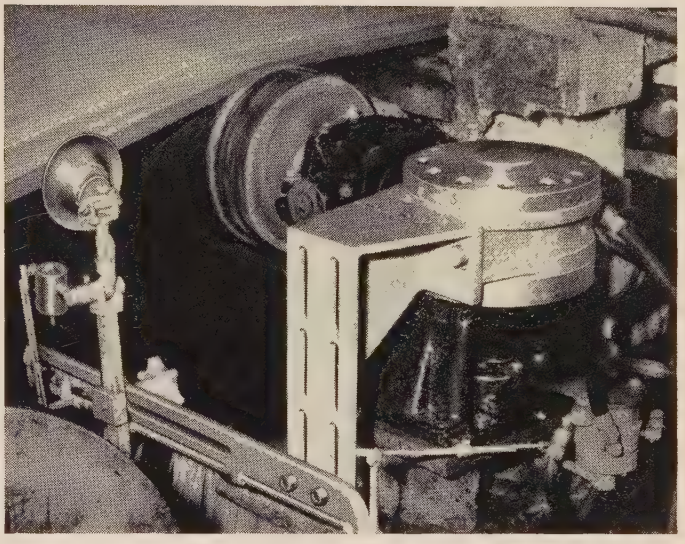
The phthalic alkyds are the most important kind of alkyds and better than 90% of all alkyds are phthalic based.

Their widespread application became practical when, after World War I, new chemical processes made phthalic anhydride available in large quantities at reasonable prices. About 60% of phthalic anhydride production of 227 million pounds in 1953, went into alkyd resins. At about 20 cents per pound phthalic anhydride remains the lowest cost polycarboxylic acid available and so meets with increasing favor in the highly competitive paint industry. The lowest cost source of organic acids, tall oil, is thus a suitable companion material.

The utility of oil modified phthalic alkyds is also being improved by the substitution of maleic and fumaric acids for some of the phthalic anhydride. Here again low cost tall oil reduces the burden of using these more expensive acids.

While phthalic anhydride has been the only form of phthalic acid of commercial importance for alkyds, isophthalic and terephthalic are also becoming available. These appear to be more reactive and there is some evidence that better oil modified alkyds result.

Phthalic alkyds are simple to make and some are still made in direct-fired open kettles. However, higher standards of



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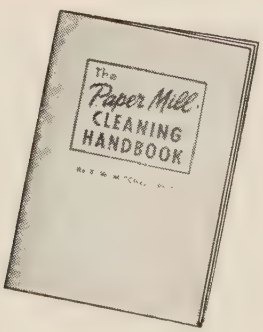

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quality and price competition have nearly eliminated such operations. As a rule plants are modern, using large, closed, stainless metal kettles with agitators, with close temperature control using indirect heating and cooling, and with accurate measuring devices for all ingredients.

One frequently used procedure for making tall oil modified phthalic alkyds is to heat the tall oil with the desired polyols at esterification temperatures. After an hour or so, some of the water formed in the reaction has distilled out and the partially reacted mixture is nearly homogeneous. The phthalic anhydride is then added and the heating continued at some prescribed temperature, depending on the polyols used, until the desired acid number and viscosity are reached.

Tall oil may also be used together with any of the natural glyceride oils to make oil modified alkyds. A common practice is first to heat the glyceride oils at esterification temperatures with the desired polyols. The polyols thereby interesterify with the glyceride oils and some or all of the glyceride oil is reduced to monoesters or diesters. Any residual polyol is more soluble in these than in the natural triglycerides. The tall oil and the phthalic anhydride are then added and heating continued at some prescribed temperature to a desired acid number and viscosity.

In many instances, especially where agitation is adequate, all ingredients are added at the start and the cooking proceeds much as in simple esterification. Mineral spirits are refluxed to remove the water formed in the reaction and to seal the kettle against air.

References: 9, 11, 24, 25, 26, 32, 35, 36, 37, 39, 46, 47, 48, 52, 54.

Maleic Alkyds

Maleic anhydride production has been declining somewhat and amounted to only 19 million pounds in 1953 but its importance is much greater than this ratio to phthalic anhydride would indicate. Much of it goes into phthalic alkyd modifications especially where tall oil is used. Its relatively high price, about 7 cents a pound higher than phthalic anhydride, and its greater functionality probably contribute to the lower volume of use.

Maleic anhydride forms adducts with the rosin acids in tall oil so that their compound becomes a tricarboxylic acid. The higher functionality of the compound thus leads to esters of higher melting point. Thus, where a rosin pentaerythritol ester shows a melting point of about 110°C., a high maleic adduct ester melts at about 145°C. Using sorbitol pentaerythritol mixtures, esters have been made with a relatively high maleic content rosin adduct having a melting point of 155°C.

The higher functionality of the rosin adduct leads to harder resins though at the expense of some solubility and compatibility. The color stability on aging is much improved over that of plain rosin esters.

The rosin acids in tall oil are present as various isomers and these vary in their readiness to form the maleic adduct. The levo-pimaric isomer reacts more readily than the abietic isomer and heating favors a shift to the former. Accordingly while adducts form at lower temperatures, heating to 450–470°F. increases the conversion. The fatty acids of tall oil, mainly oleic and linoleic, also form adducts with maleic anhydride. In any case it is desirable for the stability of the final product that all the maleic anhydide be reacted before the polyol is added for esterification. Complete reaction is readily demonstrated by a dimethyl aniline test.

References: 4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 17, 22, 23, 31, 33, 38, 40, 41, 42, 44, 47, 48, 49, 50, 53.

Fumaric Alkyds

Fumaric acid is in a still smaller but growing volume of production, near 6 million pounds during 1953. It competes

with its isomer, maleic acid, and its anhydride. About 1.6 million pounds of fumaric acid were used in 1953 to modify phthalic alkyds.

Fumaric acid forms adducts with rosin acids and unsaturated fatty acids much as does maleic anhydride. The rosin adducts form more readily than with maleic anhydride and the melting points of the fumaric adduct esters are about 25°C. higher than those of maleic. About 55,000 lb. of fumaric acid were used in 1953 as additions of 2 to 10% to improve the properties of tall oil esters. With increasing supplies of this interesting chemical, chemists will probably develop many new potentialities for tall oil.

References: 22, 31.

Other Alkyds

The present clarified understanding of the relations between the properties of resins and their chemical structure has enabled chemists to move boldly into the design of very novel resins of remarkable properties. While often the chemicals needed are still too expensive, a definite demand will lead to abundant supplies at reasonable prices. The low cost of tall oil has speeded developments of this kind in an increasing number of instances with many more in prospect. Some of these will be the subject of future Bulletins.

References: 13, 16, 19, 20, 21, 26, 33, 40, 41, 42.

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The references following are limited to those where tall oil is mentioned. Regrettably, space would not allow the inclusion of the enormously larger number of items dealing with rosin and with fatty acids. These are closely related to tall oil and this large literature contains much more data and many more suggestions for users of tall oil.

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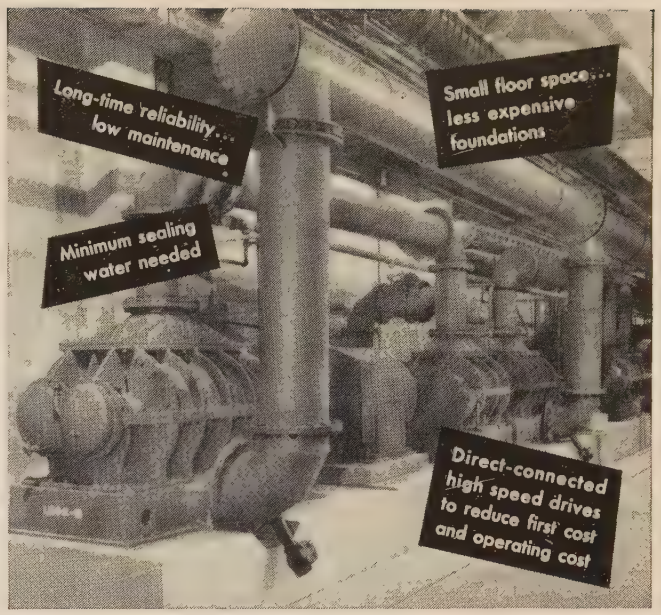
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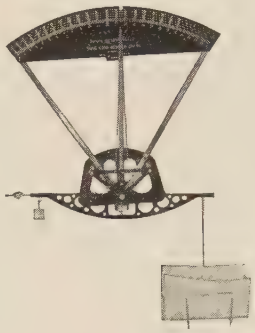

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Tree Prunings for Mineral Detection

The mineral prospector has a new tool to aid him in his search for rocky riches. Two enterprising geologists at the University of British Columbia have come up with a practical method of analyzing tree prunings to determine the existence of minerals in the earth beneath the tree.

Trees contain a certain amount of minerals and when the normal amount has been determined for each tree and each mineral the scientists have a measuring stick. If prunings from a tree show a higher content of a particular mineral than is normal for that area and species a deposit of the mineral is indicated.

Accident Rates

The National Safety Council, 425 N. Michigan Ave., Chicago, Ill., has issued its "Accident Rates" booklets for 1953. The booklet for the Pulp & Paper and Printing & Publishing industries gives current accident rates and a summary of rates for some years back, and shows how the industry stands with respect to 40 industrial classifications.

Western Michigan

With the purchase of complete equipment from the Federal Government, the Western Michigan College paper technology department has added microbiology facilities. Although no courses in microbiology are taught at the present time in the department, the equipment is being used by senior students engaged in thesis projects.

Enrollment in the paper technology department this Fall has hit a new high of 92 students, with 84 of them actually majoring in paper technology. To meet this anticipated increase, Robert N. Zabe was added to the paper technology faculty this Fall.

U. of Alabama

Eighteen representatives of the pulp and paper industry met with chemistry and engineering teachers of the University of Alabama recently to discuss the needs of industry and the university. I. Y. Yeast, International Paper Co., Mobile, Ala., stressed the need for technical men well grounded in

President O. C. Carmichael of the University of Alabama addresses delegates at the pulp and paper conference held recently at the University. Seated at President Carmichael's right are H. D. Warner, board chairman of Gulf States Paper Corp., and Mrs. Mildred W. Warner, president of Gulf States

fundamentals rather than those who have taken specialized courses. Jack Warner, Gulf States Paper Corp., discussed what industry can do to help by providing scholarships and forwarding educational programs.

The program included a tour of the facilities being set up for the pulp and paper courses and being supervised by James Ayer, asst. professor of pulp and paper technology.

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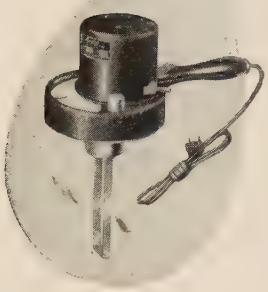

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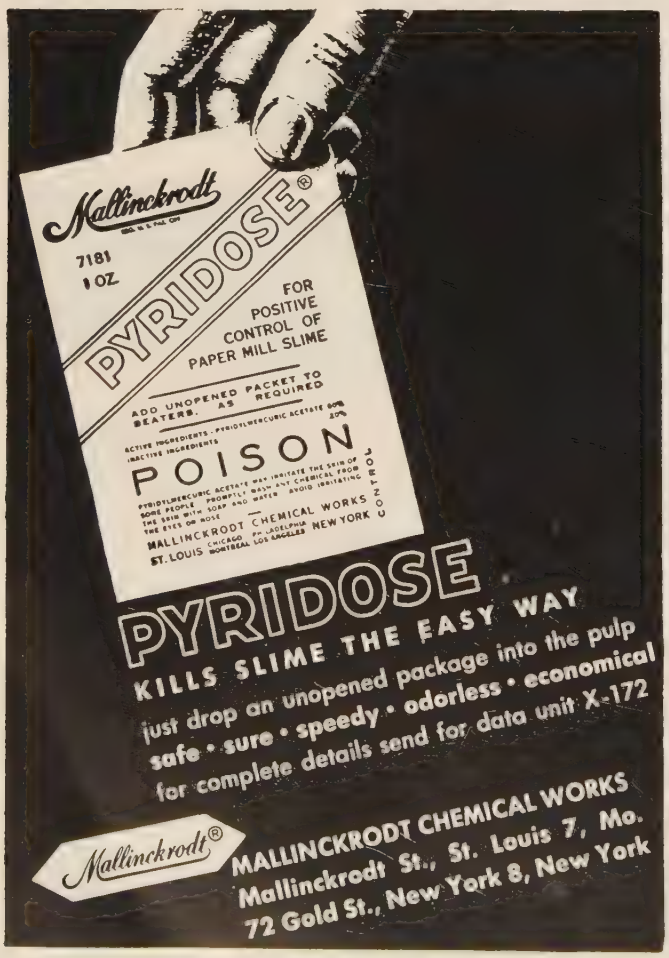
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RHINELANDER

The largest volume of torula yeast ever made in a single day was produced at Rhinelander, Wis., recently by Lake States Yeast Corp., subsidiary of Rhinelander Paper Co. Output for the 24 hours was 15,200 lb., almost double the 7700 lb. per day capacity for which the plant was originally designed when built in 1948 to utilize sugar in spent sulphite liquor that formerly was discarded into the Wisconsin River.

Complete success in producing an entire new class of by-products from pulp and paper industry sources was jointly announced by Rhinelander and Schwarz Laboratories Inc., Mount Vernon, N. Y., manufacturers of fine chemicals. Expectation is that this may open broad additional markets for torula yeast.

The first product thus developed is nucleic acid. Medical science in recent years has focused much attention on geriatrics, which is care of the aged. Nucleic acid is essential for the growth and proper function of all living cells, and is therefore especially important in studies of growth and aging. For many years it has been used as a tonic base in Europe. Several medically important compounds are derived from or related to nucleic acid. The two companies plan to extend this development to include the recovery of other compounds in yeast which are needed for medical research in human and animal nutrition.

ST. REGIS

St. Regis Paper Co. has completed arrangements for the sale of its Watertown, N. Y., paper mill to the Aco Machinery Co. of which Abe Cooper of Watertown is owner.

Mr. Cooper was president of Bagley & Sewall, paper machinery manufacturers of Watertown, which firm was sold recently to Black-Clawson Co. Mr. Cooper has indicated that he will make the mill his headquarters and continue its operation.

The mill's equipment consists of one 70-in. and one 84-in. cylinder paper machines with a maximum trimmed sheet of 74 in.; and one 57 1/2-in. coating machine. The mill produces No. 1 rope, jute, kraft, and composition cylinder papers and has a daily capacity of 50,000 lb.

P. M. Dunn, St. Regis Paper Co.

Paul M. Dunn, presently dean of forestry at Oregon State College, will be appointed technical director of forestry for St. Regis, effective Jan. 1, 1955. Mr. Dunn succeeds A. B. Recknagel who retired Dec. 31, 1953, but continues in a consulting capacity with St. Regis.

As technical director of forestry, Mr. Dunn will make his headquarters at the St. Regis New York Office. He will work closely with St. Regis forestry, woodland, and procurement personnel as well as with national and regional government forestry agencies and trade associations.

WEST VIRGINIA

A revolutionary grade of liner board, used in the manufacture of corrugated shipping containers, has been developed by West Virginia Pulp & Paper Co. The new product, to be marketed as ISL (Improved Surface Linerboard), is an unbleached liner board with unique characteristics which will improve the appearance and serviceability of corrugated boxes. Company officials report that the color, surface, and

ink receptivity of the new board are superior, while its strength characteristics are equal to any natural finish kraft liner board now on the market.

Due to operating efficiencies achieved through the company's patented processes, the new board will be offered at the same price as regular liner board. The new board will be marketed in all the normal basis weights.

ISL consists of a 100% pine kraft primary sheet, combined with a secondary surface layer made from kraft hardwood pulp, which is produced by the company's patented hydrothermic injection pulping process.

The special secondary surface layer which is applied as the kraft sheet is formed on the paper machine, eliminates the surface voids found in natural kraft liner board and provides a much smoother printing surface for box makers. Tests also show that the new board has more uniform ink receptivity, another factor which adds to the printing quality of the board, especially where ink is laid over large areas.

In addition to qualities which improve the appearance of corrugated boxes, tests of scuff resistance show that the surface is considerably stronger than natural finish kraft.

Engineering for a new fourdrinier kraft machine and supporting equipment at the Charleston, S. C., mill of West Virgina, estimated to cost between $10,000,000 and $15,000,000 was authorized recently.

Preliminary studies indicate the new machine will be a high capacity fourdrinier capable of producing a sheet about 18 ft. wide at speeds higher than any machines making comparable grades today.

The new machine will enable the mill to increase its production of improved surface liner board, which the company has just started making for the corrugated box industry, and kraft paper, used principally in the manufacture of multiwall bags for shipping such products as cement, fertilizer, sugar, foods, and chemicals.

Gulf States

The Gulf States Paper Corp. and its sales division, the E-Z Opener Bag Co. of Tuscaloosa, Ala., has purchased a plant site of 1550 acres on the Tombigbee River, approximately six miles downstream from the Demopolis lock and dam.

The huge plant site, which is traversed by U. S. Highway Number 80, is located approximately eight miles southwest of the City of Demopolis. The Southern Natural Gas Co.'s pipe line and a power transmission line run through the property.

The site was purchased in order to provide a location for further expansion of the Manufacturing Division of the company.

Southern Chemical Cotton

Southern Chemical Cotton Co., of Chattanooga, Tenn., one of the major producers of cellulose from cotton linters, is expanding its facilities by the addition of a new purification plant. The expansion consists of a new building housing equipment to continuously cook, wash, and bleach approximately 200 tons of finished linters (chemical cotton) per 24 hours. This addition is under construction, and is expected to be in operation in March, 1955. J. E. Sirrine Co., Greenville, S. C., are the engineers for the project.

American Viscose

In the printing of cellophane, the heat applied to set the ink drives considerable moisture from the film. The film producers and converters have recognized for a long time the desirability of replacing the moisture loss in the printing process.

With this in mind, John Conti, head of the Technical Service of the Sylvania Division, American Viscose Corp., went to work on the problem.

After several years of both laboratory and field tests, the Sylvania web conditioner became a reality. Close collabora-

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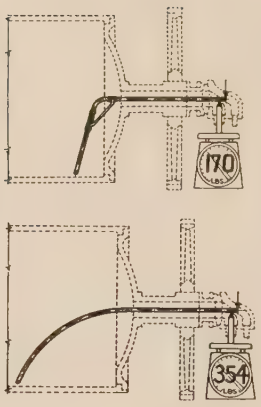

Here is a syphon that features a brace, a spring and low cantilever leverage on the steam joint.

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The leverage on the "joint" is only 170 lbs. in contrast with 354 lbs. usually exerted by the conventional straight pipe. Thus excessive wear on the "joint" is avoided.

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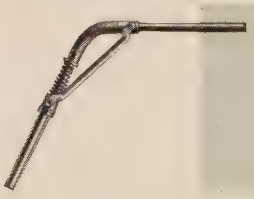

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tion between Mr. Conti and Stewart W. Speers, of the S. W. Speers Co., Philadelphia, builder of the units, is now paying off in moisture dividends in many converting plants throughout the country.

The conditioner is installed at the end of the processing line, and the automatic controls are synchronized with the press. As the press starts and stops, the conditioner turns on and off. The temperature maintained in the unit is a constant 190°F., and the steam pressure ranges between 3 and 5 p.s.i.

As the film comes off the press after printing at anywhere from 50 to 550 f.p.m., and enters the conditioner, there takes place a slight flowing action on the film surface. The pin-pointed steam jets are already open and are driving the moisture from all angles into the base web of the film.

Rome Kraft

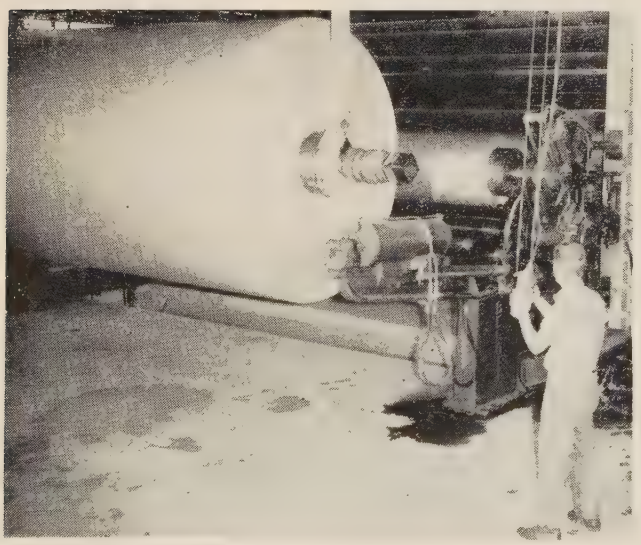
The new container board plant of Rome Kraft Co. is now in operation. The plant represents an investment in excess of $25,000,000.

Construction was begun in July, 1952, under the Government's Necessity Certificate Program of increasing the Nation's productive capacity. The plant, which has 7 acres of floor area inside its buildings, is located on the Coosa River, 10 miles west of Rome, just off State Route 20. It is served by the Southern Railway System and the Central of Georgia Railroad.

Rome Kraft will produce over 650 tons of container board daily—over 200,000 tons annually. The plant will employ 600 people when peak production is reached at an annual payroll of about $2^1/_2$ million. Built in the center of a rich pine country, Rome Kraft will draw its pulpwood from Northwest Georgia, Alabama, and Tennessee. Thirteen hundred cords of the three major native varieties of pine—shortleaf, Virginia pine, and loblolly—will be converted into container board daily. Supplying the pulpwood, the major part of which is purchased from farmers and landowners, will provide employment for about 1200 people in the various woods operations.

Rome Kraft through its subsidiary, North Georgia Timberland Co., is developing in excess of 300,000 acres for pulpwood production with a staff of trained foresters employing the latest scientific land management practices. About 3 million pine seedlings are being planted on these lands annually in addition to the free distribution of 2 million seedlings to farmers and land owners throughout the area each year.

Rome Kraft Co. is owned by the Mead Corp. of Dayton, Ohio, and the Inland Container Corp. of Indianapolis, Ind., who also own Macon Kraft Co., Macon, Ga. Herbert A. Kidd is vice-president and general manager of both operations.



Jack Shiver, paper machine crewman, is operating the controls of a crane lifting a 24,000-lb. roll of container-board from the paper machine at the new Rome Kraft Co. plant. More than 50 rolls of this size will be made each day when peak production is reached

Alaska Pine & Cellulose

Arrangements have been concluded under which Abitibi Power & Paper Co., Toronto, Ont., and the Koerner interests of Vancouver, B. C., expect to sell to Rayonier Inc., New York, N. Y., a majority of their holdings in the common stock of Alaska Pine & Cellulose Ltd, Vancouver, B. C.

A total of 80,000 shares of Alaska Pine & Cellulose stock is involved, valued at approximately twenty million dollars. Both the Abitibi and the Koerner interests will retain a substantial stock interest in Alaska Pine & Cellulose and D. W. Ambridge and Walter Koerner will continue as directors of the company.

Brown

What would you do if somebody asked you to determine the quantity of wood in the Androscoggin River above Berlin? Don't bother. . . somebody else has already done it.

It was all a result of a problem which recently developed in the woods department. They wanted to know how much wood was being stored in the river. But, in order to determine how much wood was stored there, it was necessary to find the width of the river at certain points.

Kenneth Lambert, assistant to chief scaler, hit upon a scheme. He borrowed Bill Johnson's skis, hooked one end of a light rope to his belt and started across the river of logs . . . on skis. And strangely enough, it worked.

When Lambert arrived at the other side of the river the rope was pulled back and then measured to determine the exact width of the river at that particular point.

With the width of the river determined, the length of certain sections was also measured. With these two distances known it was then possible to determine the quantity of wood in that particular section of the river.

According to woods department officials, it was the most accurate measurement ever made of the river's width except naturally, during the Winter months when the river crew can walk over the frozen surface of the river.

The "skiing" scheme worked out so well that the woods department is seriously thinking about designing special type skis to be used for this purpose wherever and whenever needed.

—from *Brown Co. Bulletin.*

Olin Mathieson

Construction of a second plant to manufacture Olin cellophane is expected to start about March 1, 1955, on a site to be known as Olin, Ind., located on the Wabash River between Covington, Ind., and Danville, Ill. The plant will be engineered and constructed for Olin Mathieson Chemical Corp. under contract with E. I. du Pont de Nemours and Co. Olin's first cellophane plant at Pisgah Forest, N. C., has been in operation for over three years.

Gair

Charles Swerdlove has been appointed assistant to W. W. Scheide, folding carton division, Robert Gair Co., Inc., New York, N. Y.

Rayonier

A 31,095-acre tree farm has been established as a part of the forest holdings of Rayonier Inc. in the Pacific Northwest. Known as the South Harbor Tree Farm, it was certified by the Industrial Forestry Association meeting at Portland, Ore.

The new tree farm is an additional step toward bringing all of the company's 861,969 acres of forest properties to the optimum seed-growth-harvest cycle.

GLATFELTER

More than 5000 persons toured the enlarged plant of the P. H. Glatfelter Co., Spring Grove, Pa., during its three-day open house and 90th anniversary celebration on Oct. 7, 8, and 9.

Tour guests watch a rewinder in operation at the P. H. Glatfelter Co. mill

The celebration opened with a cornerstone laying ceremony at the new bleach plant on Thursday afternoon, October 7, with P. H. Glatfelter, III, president, addressing a group of more than 200 paper industry executives and York, Spring Grove, and Hanover civic leaders.

The cornerstone laying ceremony represented the completion of the company's latest expansion program which represented an investment of more than $4,000,000. It included the new bleach plant and chlorine dioxide generating equipment which makes it the first paper plant in the United States using a three-stage chlorine dioxide bleaching process. The expansion also included a new chemicals recovery plant for the recovery of chemicals from the cooking liquor.

P. H. Glatfelter, chairman of the board, laid the cornerstone assisted by A. C. Miller, paper mill superintendent and president of the company's Quarter-Century Club. A

A tent was set up at the end of the P. H. Glatfelter Co. plant tour to show the end use of the papers made, the growth of the company, the role of the company and its employees in the community, the importance of the paper industry, and the progress made in forest conservation

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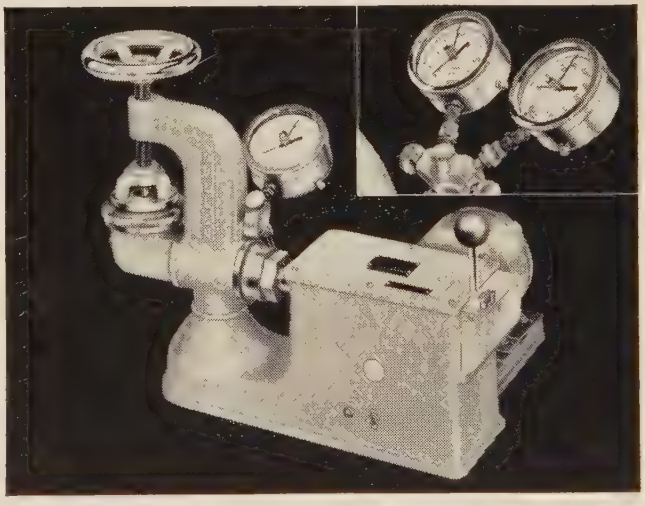
Model A—Motor Driven



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copper box containing certain records of the occasion was placed behind the cornerstone by Mr. Glatfelter.

Western Kraft

A multi-million dollar kraft paper plant will be built at Albany, Ore., by the newly formed Western Kraft Corp. Ira C. Keller, of Portland, is president of Western Kraft; Sandwell and Co., of Vancouver, B. C., are consulting engineers on the project.

Plant output of the new Albany mill will be 100 tons of kraft container board per day. The new plant is scheduled for completion in December, 1955. Engineering plans are well under way, and bids for construction will be issued shortly. The Seattle and Portland operations of Sandwell and Co. are directed by A. E. Frankfurter, resident engineer.

Mr. Keller was formerly executive vice-president of Container Corp. of America.

Fraser

The following changes have been made in the Technical Department of Fraser Cos., Ltd., Edmunston, N. B.: W. A. Ketchen has been appointed to the new position of technical director and A. J. Corey succeeds him as chief chemist. Following these appointments, Karl Patrick has been named assistant chief chemist to succeed Mr. Corey and W. H. Birchard has been appointed chemical engineer, special assignments of the technical department.

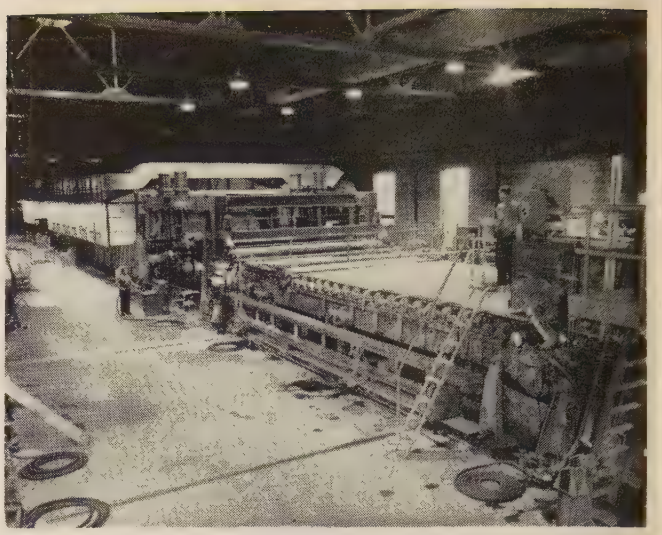
Fraser's new paper machine, designed to produce a range of light and medium weight bleached chemical wood pulp papers, is now in operation at Madawaska, Me.

This machine replaces the original no. 4 machine installed in the mill in 1928, three years after the mill began operations at Madawaska. The old machine was shut down in June of this year and was dismantled and sold for use elsewhere.

Manufactured by Pusey and Jones Corp., the new machine incorporates the latest principles in the engineering of papermaking equipment. With over-all dimensions of some 300 ft. in length and 55 ft. in width, it is designed and physically balanced to operate up to a speed of 2000 f.p.m. and will add some 10,000 tons of paper to the mill's annual capacity.

Structural Changes. Since the new machine is wider than the old one, the pit was widened 15 in. to provide clearance for the wider driers and easier broke removal. Consequently, all supporting steel on the tending side of the machine had to be relocated. A penthouse was constructed to house the ventilating fans and economizers. A new electric substation was also erected on the west side of the mill. On its ground floor are housed the motor-generator sets and motor controls for the major units of the machine. The second floor accommodates stock preparation equipment.

Stock Preparation. A new tile beater dump chest and tile machine chest were built. Four Morden stockmakers and a DeZurik consistency regulator were installed. There are



At the wet end of the new no. 4 machine of Fraser Paper, Ltd. may be seen the Beloit pressure headbox, stainless steel fourdrinier, and simplex press arrangement

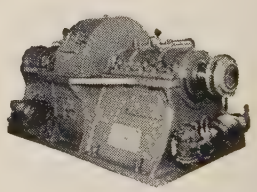
two Goulds fan pumps having a capacity of 12,000 g.p.m. at 40-ft. head. A system of Bauer Centri-Cleaners is located ahead of the four 2A Bird screens. Each fan pump has air-operated throttling valves. The flow from these is automatically controlled from the level of stock in the Bird screens. All stock and white water piping is made of stainless steel or copper.

Headbox and Wire. The machine is equipped with a Beloit air-cushioned headbox with stainless steel lining. The fourdrinier takes a 196-in. by 94-ft. 2-in. wire. It has a dual breast roll arrangement, micarta tipped forming board, and micarta deflectors. All parts of it in contact with the stock are sheathed in stainless steel. The table rolls are rubber covered and the wire return rolls are of stainless steel. The suction couch roll is 44 in. in diameter with a 6 to 10-in. adjustable suction box. There is a 24-in. separately driven dandy roll and a lump breaker roll with air-loaded cylinders. The wire stretch rolls are raised and lowered hydraulically.

Press Section. The press section is a Simplex type having two 36-in. diameter rubber-covered suction press rolls, the first press having a 4-in. suction box and the second press having a 4 to 8-in. adjustable box. The felt stretchers are operated by air motors. Felt cleaning is accomplished with suction boxes and Vickery felt conditioners. The bottom roll only of a future smoothing press is located in the receiving drier position.

Pre-Drier Section. In the pre-drier section there are 23 paper driers of 5 ft. in diameter, 8 felt driers of the same diameter, and one transfer drier 3 ft. in diameter. All driers are

proven
by
performance



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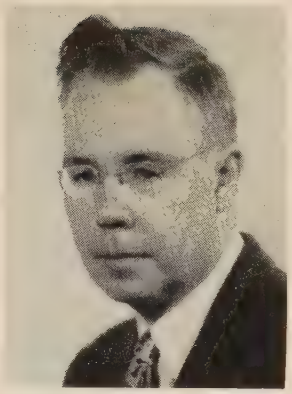
*U. S. Patent No. 2,654,295

W. A. Ketchen, Fraser Companies, Ltd.

A. J. Corey, Fraser Companies, Ltd.



Karl Patrick, Fraser Companies, Ltd.

W. H. Birchard, Fraser Companies, Ltd.

built for 75 p.s.i. steam. The gear train is enclosed and antifriction bearings are used throughout on the driers and felt rolls. The automatic felt stretchers are motor driven.

Yankee Drier. The Yankee drier is 12 ft. in diameter and built for 125 p.s.i. It is equipped with Sunday drive. Two pressure rolls of 24 in. in diameter are used. The rope system for carrying the paper is so arranged that the paper can by-pass the Yankee drier if desired.

Size Press. The size press is equipped with a rubber-covered bottom roll and a pneumatically loaded brass top roll. It is followed by a steam-heated 24-in. set roll separately driven and a Mt. Hope expander roll. If necessary, the size press can also be by-passed.

After-Driers. In this section there are eight paper driers of 5 ft. in diameter each and built for 125 p.s.i. The gearing is enclosed and there are antifriction bearings throughout. The felt stretchers are motor driven and operate automatically.

Calender Stack. The calender stack has eight rolls carried in steel frames and antifriction bearings. The rolls are raised, lowered, and loaded hydraulically. The bottom roll is of the antideflection type. The doctors are pneumatically loaded and hydraulically oscillated.

Reel and Winder. The reel is a Pope type with horizontal track, pneumatically loaded. There is a motor accelerator for reeling mandrels. The reel drum is water cooled. The winder is Cameron type 19. It has an hydraulically operated roll lowering table for removing rolls from the winder.

Oiling System. All drier bearings, enclosed gearing in drier sections, and calender roll bearings are automatically lubricated. The capacity of this system is approximately 4500 gallons.

Drive. The machine is driven by a Reliance sectional generator type drive having a range of from 500 to 2000 f.p.m. A slack take-up is used on the calender section only. In addition helper drives were supplied for the following units: first return wire roll, dandy roll, lump breaker roll, couch draw roll, Yankee pressure roll, and size set roll. The motors are force ventilated by a central cooling fan and ductwork system. The controls for the individual drive motors are located in console type panels on the tending side of the machine which also contain controls for much of the auxiliary equipment.

Drier Drainage System. The drier drainage system was supplied by Midwest-Fulton. A separate 250-lb. steam line was installed for the Yankee drier direct from the boiler house with pressure reducing and desuperheating equipment. Steam for the predriers and afterdriers, as well as the felt driers, is supplied from the extraction steam from the turbines at 25 p.s.i. By means of differential controls, various sections can be supplied from the flash steam from the other sections. The first six driers in the predrier section and the first four driers in the afterdrier section can be individually controlled to provide graduated temperatures.

Ventilating System. Ross open hoods and ventilation system with stainless steel economizers are installed on the machine. The Yankee drier is equipped with an exhaust fan, economizer, and supply fan for a vapor absorption system. No economizer is used on the afterdrier section. Two fans supply outside air to the center aisle of the machine room. In the basement there are three units for the felt drying system. All supply fans are equipped with filters and automatic face, by-pass, and recirculating dampers.

Starch System. Two stainless steel starch tanks of 200 gallons capacity each were erected to hold the starch to be supplied to the machine. These tanks are fed automatically from a central starch preparation system.

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Sutherland High Yield Kraft System*

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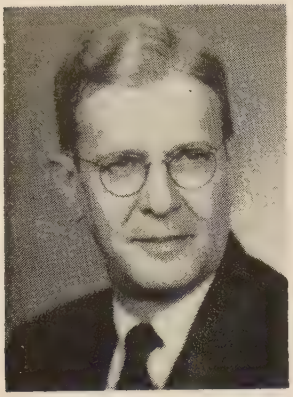
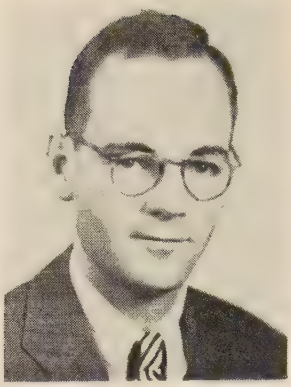


N. W. Coster, Scott Paper Co.



C. D. Dickey, Jr., Scott Paper Co.

Edwards Paper Co.'s proposed sulphate pulp mill addition for hardwoods was obtained recently when 68 cords of oak pulpwood were processed through the present plant.

The objects of this mill scale run were to obtain firsthand design information for equipment for the new plant, to check the small-scale research results on pulping and bleaching, and to obtain sufficient pulp for a preview of its actual use in papers.

Downingtown Paper Box

Downingtown Paper Box Co., Downingtown, Pa., is successfully operating a gasoline-powered fork-lift truck equipped with an OCM catalytic exhaust. The OCM unit, manufactured by Oxy-Catalyst, Inc., Wayne, Pa., proved completely successful in getting rid of carbon monoxide and noxious hydrocarbons from the engine exhaust.

Columbia River

George H. McGregor has been appointed general superintendent of the Vancouver, Wash., mill of Columbia River Paper Mills.

Scott

The following personnel changes have been made recently in the West Coast division of Scott Paper Co.: Leo S. Burdon, assistant vice-president, will delegate some of his direct manufacturing responsibilities in order to devote more time to long range planning and to projects connected with the three West Coast mills.

All pulp and paper production and certain supporting departments at Everett will henceforth be the responsibility of three staff assistants to Paul C. Baldwin, vice-president.

N. William Coster, as pulp mill manager, will have the responsibility for the expanded pulp and wood preparation and for the yard crews.

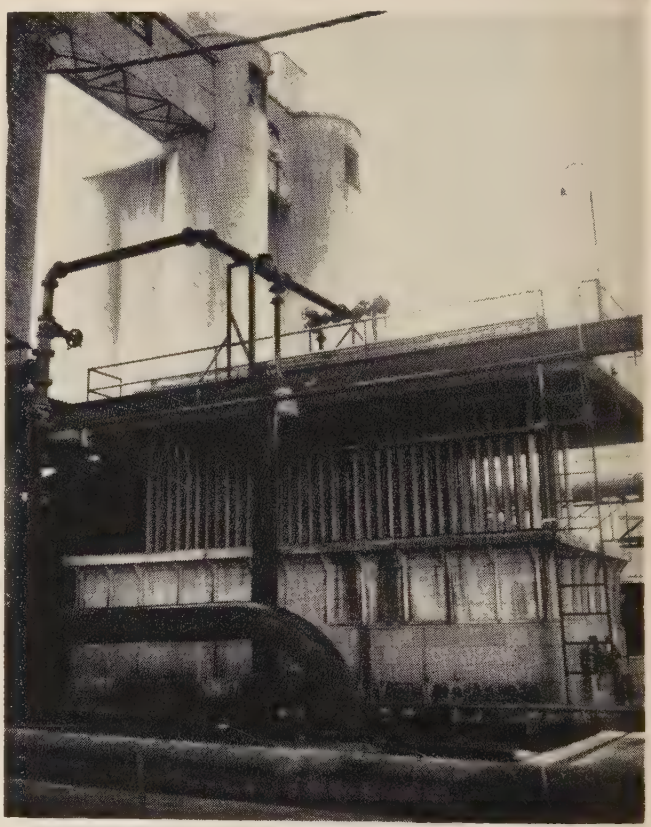
Loren V. Forman, as technical director, will continue to direct the pulp and paper technical control sections, Research and Instrument Departments, and in addition, will have the over-all responsibility for paper mill operations and for the Engineering and Maintenance Departments.

Charles D. Dickey, Jr., will become administrative assistant and will assume general direction of the Accounting Department, the Log Purchasing, Taxation and Insurance Department in addition to his present Purchasing, Traffic, and Stores responsibilities.

Scott's expansion program on the West Coast assumed major proportions at Everett, Wash., during the year 1954.

The over-all project was concentrated in two areas—the continued building of the paper mill and the addition of facilities in the pulp mill. The latter was already the largest bleached sulphite mill in the world.

In December of 1953, the first high-speed paper machine in the company's new West Coast paper mill went on the line. The second machine followed a few months later. Installation of supporting equipment, shipping, and converting



Jensen cooling system, used in making ammonia cooking solution, installed during expansion of pulp mill

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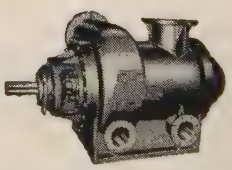
performance



Sutherland Breaker Trap

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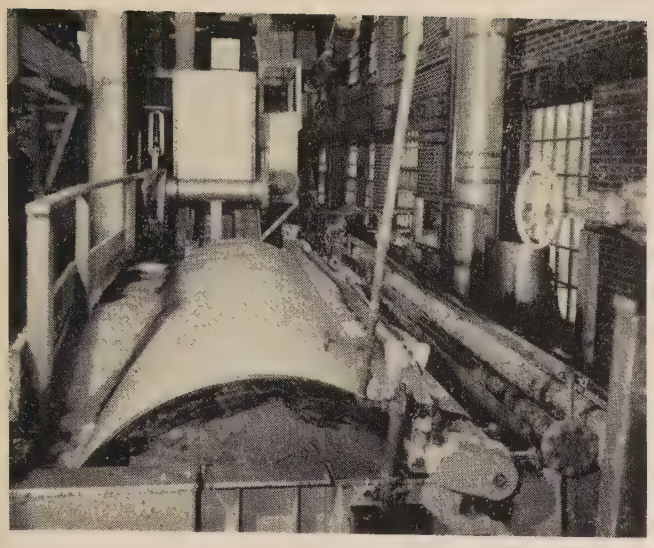


New Impco valveless decker used in washing bleaching ingredients from stock. Scott Paper Co., Everett, Wash.

facilities went into operation at the same time. The paper mill is currently producing, finishing, and shipping a number of Scott products.

The year 1955 will see the installation of two more high-speed paper machines and related equipment which will be housed in another new section of the paper mill, construction of which is now under way.

Culminating many months of engineering and construction, pulp production facilities of the plant have been increased to over 700 tons daily of high quality bleached sulphate. Research started several years ago in the use of ammonia instead of calcium in the preparation of the cooking solution, which enables the use of species of wood not heretofore employed in the manufacture of sulphite wood pulp. A second reason for this expansion was to make available to Scott plants throughout the country, and to the company's pulp customers, additional annual tonnage of bleached grades of sulphite pulp.

The research was the result of an effort on the part of the company to use several other species of timber found on the western slopes and thus bring about a more complete utilization from the logging of its total acreage of timber holdings.

Grace

A one-and-one-half million dollar project to provide a 50% increase in production at the Grace bagasse pulp and paper mill at Paramonga, Peru, has been started by W. R. Grace & Co.

The project includes the purchase and installation of a 110-in., five-cylinder paper machine now being built by the Sandy Hill Iron and Brass Works. Designed to the most up-to-date standards of the United States paper trade, the machine will produce various grades of board, including coated stock.

The machine, which will be placed in operation during 1955, is engineered to run 300 f.p.m. and to produce initially 30 to 50 tons per 24 hours. It can be expanded, however, to produce as much as 80 tons a day to keep pace with projected market growth.

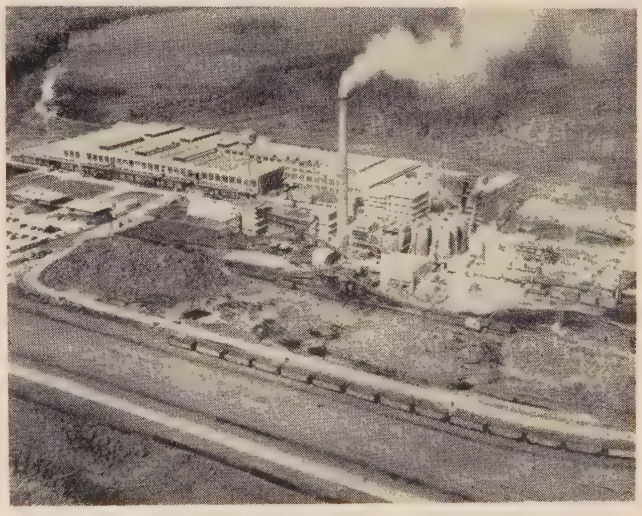
The Paramonga mill was the first in the world to produce paper from bagasse on a commercial scale. Bagasse is the residue of the sugarcane grinding operation and its traditional use has been as a fuel for sugar mill boilers. In the sugar manufacturing process there is approximately a ton of bagasse fiber for every ton of white sugar produced.

Hudson

A $15 million expansion program, including installation of a high-speed paper machine, is to be undertaken by Hudson Pulp & Paper Corp., New York, N. Y., at its Palatka, Fla., division. The new mill will be the first fully integrated tissue product manufacturing operation in the South. The fourdrinier paper machine will have an 80 ton a day capacity, and will be used to make facial and toilet tissue and household napkins from bleached sulphate pulp.

Contracts for the project, which will require about 20 months to complete, will be awarded by J. E. Sirrine, Engineers, Greenville, S. C., as soon as details are completed.

In addition to the paper machine, which will supplement the two machines now in operation at Palatka, the expansion



Aerial view of the Palatka, Fla., plant of the Hudson Pulp & Paper Corp.

proven by performance

Sutherland Inc. Pressure Washing*
Sold and Serviced by

PRESSURE WASHING

SUTHERLAND REFINER CORPORATION
TRENTON 8, NEW JERSEY

*U. S. Patent No. 2,355,091

program will include pulp driers, three digesters, a bleach plant, chemical recovery equipment, water treatment and filtration plants, turbines, and converting equipment.

Penobscot Chemical Fibre

Penobscot Chemical Fibre Co., Great Works, Me., has awarded its annual scholarship of $400 to Wilma Brown, daughter of Ara Brown, digester cook's helper in the Penobscot pulp mill.

National Vulcanized Fibre

National Vulcanized Fibre Co., Wilmington, Del., has published a booklet portraying the company's vulcanized fiber products in the role of a detective, Sherlock Fibre, who solves tough production and design problems.

National has merged its Fibre Specialty and Phenolite Div. to form the Kennett Plant in Philadelphia.

Henry C. Guhl has been named National's manager of process engineering in charge of manufacturing specifications and control and quality control.

Espanola

Pulpwood supplies are obtained from the forest, and in the case of Kalamazoo Vegetable Parchment Co., Espanola, Ont., jack pine, poplar, and spruce are the most important species. Our forest area lies to the north of Espanola and is known as the "KVP Concession Area." By agreement with the Ontario provincial government, made in 1943 prior to the construction of the mill, and in order that we might have an assured source of pulpwood supply, KVP was granted cutting rights on this area.

We have found that the area is growing sufficient wood annually to maintain our pulp mill operations. The areas where forest crops are ripe and ready for harvest are known, and we have located the stands of younger trees from which future crops will come.

We have built to date and are currently maintaining 128 miles of permanent gravel roads. It is estimated that at least 500 miles of permanent roads will be required to service the whole concession. In addition, there is a continuing need for many miles of semipermanent or more temporary roads to service annual cutting operations.

Camps have been built to house and service up to 1200 men—the number employed in the woods during our busy periods. Necessary supplies, food, tools, and equipment have been delivered to the camps over the road system. It takes an average of 17 tons of such materials to service the production of each 1000 cords of pulpwood.

Not many years ago all of the cutting was done with hand tools and the hauling unit was the horse and sleigh. Under these conditions, wood could be hauled and delivered only during the Winter months. Today, the power saw is replacing the buck saw and trucks and tractors are doing much of the work done formerly by horses. Good roads and mechanical equipment are making it possible to log almost the year around. This spells increased efficiency and lower costs. There is a continual search for and trial of new procedures and new types of equipment.

Rail loading facilities have been developed where the pulpwood harvest is delivered to the mill by rail. Where delivery is by floating or driving it down the lakes and streams, channels have been improved to remove obstacles, and dams have been built to store water and control river flows.

Natural regeneration replaces the crop harvested on most of the cut-over areas. In some instances, nature requires help; a staff of trained foresters is working continually on the development of techniques which will assure the continuity of the forest crops and the perpetuation of our raw material supply.

For management and administrative purposes the concession has been subdivided into operating units. In each case, cutting operations are planned and directed to insure that the harvest taken does not exceed the annual growth of the unit.

What of the future? To date less than half of the area is accessible. We must continue our process of development. We must build more roads; additional rivers and lakes require improvement; new camps will be required and new and more efficient cutting and delivery methods will be developed.

The forest is a long-term crop—in our case, an average of 70 years from seedling to harvest tree. In the planning of our woods operations we must think a long way ahead and be prepared for the continuing demands of the development of a pioneer area.

Manufacturing

Two types of wood pulp are manufactured at Espanola, groundwood and sulphate pulp. The greatest share of pulp produced is sulphate or kraft pulp.

Water is essential for the production of pulp. Espanola, located on the Spanish River, has easy access to such a water supply. The dam at Espanola also provides water power which is changed into electrical energy for both the mill and townsite.

In addition to producing groundwood and sulphate pulp, Espanola has two paper machines. Thus, the Espanola mill supplies paper for KVP's Canadian converter plants at Hamilton and Montreal and pulp for the KVP company at Parchment.

Mead

Mead Corp. is installing a new 152-in. Downingtown fourdrinier in the no. 1 machine at Sylva, N. C. It will be used to produce corrugating medium, 0.009 point, using semichemical or chestnut furnish.

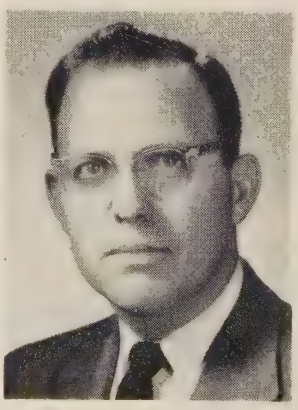
The new fourdrinier is cantilevered and stainless steel is used on all parts which are exposed to corrosion. It has 26 table rolls, a 24-in. diameter stainless steel covered breast roll, and 36-in. diameter drilled face suction couch roll.

The couch roll is mounted on antifriction bearings in a special pair of housings which are attached to the end of the main fourdrinier frames. This will eliminate the necessity of applying any cantilever stress to the couch during wire changes, the main fourdrinier frame assuming the entire load for this purpose.

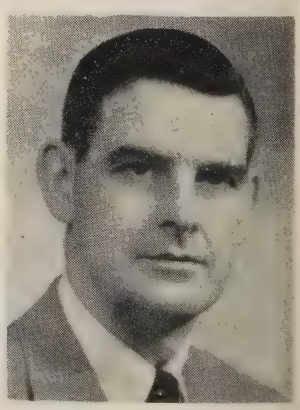
The main frame is supported by means of four unit controlled Hydrometers which may be dropped away from the bottom of the main frame for cantilevering during wire changes.

The entire save-all assembly will be designed to eliminate adjustment or removal during wire changes.

James W. McSwiney has been appointed executive assistant to the president of the Mead Corp.



J. W. McSwiney, Mead Corp.



W. L. Krapf, Bulkley, Dunton Processes, Inc.

Bulkley, Dunton

William L. Krapf has been appointed general manager of Bulkley, Dunton Processes, Inc., 295 Madison Ave., New York, N. Y.

Bulkley, Dunton has issued a new catalog of Colloidair recovery systems.

New York & Penn

New York & Pennsylvania Co., Lock Haven, Pa., has contracted with Downingtown Mfg. Co. for a 116-in. fourdrinier for its no. 5 machine. The new equipment which will be of standard design and will have 27 rubber-covered aluminum table rolls, is expected to be in operation by the Spring of 1955.

National Container

National Container Corp. officially opened its new kraft paper converting plant at Salisbury, N. C., on October 8.

Gair

Robert Gair Co., New York, N. Y., has made the following appointments: Russel D. Scribner, plant manager at Elkhart, Ind., John H. Fettinger, plant manager at Thames River Div., Uncasville, Conn., Gail E. Posson, assistant manager at Thames River.

Gilman

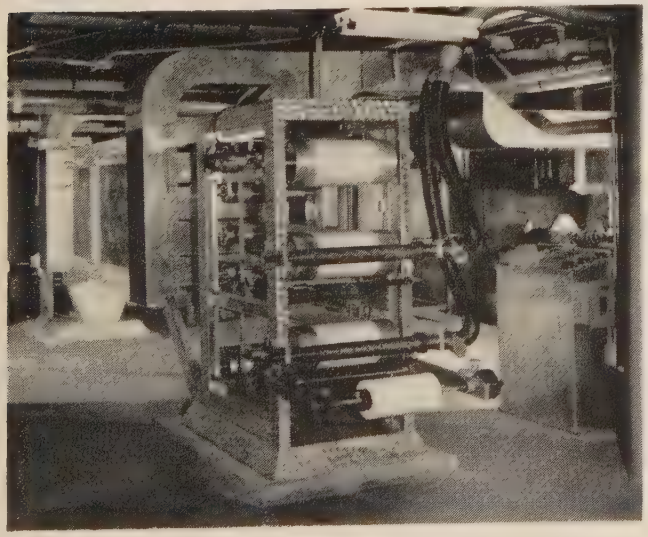
Gilman Paper Co., New York, N. Y., is now operating its pulp- and papermaking subsidiary, St. Marys Kraft Corp., at St. Marys, Ga. An important feature of the new bleach plant is flexibility of operation which permits production of practically any grade of bleached kraft. The chlorine dioxide process yields pulp of the highest brightness with little loss of strength.

Reliance

Charles F. Carnish has been appointed a district sales engineer in the Detroit district of Reliance Electric and Engineering Co., Cleveland, Ohio.

Experimental Coating Machine

The Product Research and Development Co., 4225 W. Burnham St., Milwaukee, Wis., has installed an experimental coating machine designed to apply one or two coatings to one side of a web and a decurling solution to the other side. The company intends to make the machine available to firms who wish to study coating problems.



Experimental coating machine

U. of Maine

The University of Maine, Orono, Me., has contracted with the National Council for Steam Improvement to study methods for treating spent sulphite liquor, with particular reference to Maine river conditions.

Lowell Tech

U. S. Vice-President Richard M. Nixon was awarded an honorary doctor of science degree at a special Fall convocation at Lowell Technological Institute, September 28. The

A few of the department heads and members of advisory committees are shown with the guest of the day, left to right: A. E. Chouinard; E. D. Lord, J. S. Barnet & Sons, Inc.; F. W. White, American Woolen Co.; N. M. Mitchell, Barnes Textile Associates, Inc.; Prof. John Lewis; Vice President Nixon; F. S. Klein, Byron Weston Co.; L. T. I. President M. J. Lydon, who conferred the honorary degree; Meith Maeser, United Shoe Machinery Corp.; K. E. Bell, A. C. Lawrence Leather Co.; J. A. Leroy, McLaurin-Jones Co.; Prof. J. H. Kennedy; W. B. Wheelwright; Gordon Osborne, Warwick Mills

occasion also marked the dedication of Comnock Hall, the new auditorium-administration building named in memory of Alexander Goodlet Comnock, a founder of L.T.I. and first president of the board of trustees.

FPL

The U. S. Forest Products Laboratory, Madison, Wis., is experimenting with a new kind of stadium seating made of 2-in. knotty pine overlaid with resin-treated paper and paper plastics.

For bleaching research, E. S. Lewis of FPL originated the technique of using polyethylene bags. The top of the bag can be gathered about the pipet to minimize vapor loss when introducing chlorine dioxide, and the closed bag can be kneaded to mix pulp and reagent quickly.

NCR

Formation of a new department to handle the sale and distribution of carbonless duplicating paper has been announced by The National Cash Register Co. The specially treated paper is now being made available in rolls for use on rotary presses to printing firms which manufacture business forms, following an increase in production.

The new department will be known as the NCR Special Products Department, and is headed by Clifford O. Harris, former NCR executive assistant. The department will also direct the sale and distribution of NCR porous rubber, another development of the company's Research Division. Porous rubber, which holds ink like a sponge, is widely used for price-marking stamps and other types of stamps that give hundreds of impressions without re-inking.

J. C. Standish, Albany Felt Co.

W. G. Davis, Albany Felt Co.

REICHHOLD

Reichhold Chemicals, Inc., 525 N. Broadway, White Plains, N. Y., has produced a film depicting the manufacture and uses of synthetic resins.

DE LAVAL

Harry Engvall has been appointed executive engineer of the De Laval Steam Turbine Co., Trenton, N. J. John S. Haverstick succeeds Mr. Engvall as chief engineer of De Laval's Turbine and Gear Departments.

De Laval has issued a bulletin (2203) describing their line of crown couplings.

ALBANY

Construction has been started on a new office building at the Cowansville, Que., plant of Albany Felt Co. of Canada. Also, new machinery has been ordered for the yarn winding, weaving, and finishing departments.

John C. Standish has been promoted to executive vice-president of Albany Felt Co., Albany, N. Y., Wayne G. Davis to vice-president continuing in charge of felt sales, and Harold F. Hedbert to vice-president in charge of research and development. Carl Hendricks has been appointed sales engineer for North Carolina, South Carolina, and Tennessee.

DIAMOND ALKALI

Diamond Alkali Co., Cleveland, Ohio, has begun rehabilitating the Muscle Shoals chlorine caustic soda plant which it purchased from the Government late in 1953.

ARNOLD, HOFFMAN

Arnold, Hoffman, Providence, R. I., has published a leaflet describing its line of Ahco Defoamers and their applications.

VAN AMERINGEN

The industrial division of Van Ameringen-Haebler, Inc., New York, N. Y., has adopted the name *Vandor* for all its industrial odor control materials.

G.E.

General Electric Co., Schenectady, N. Y., has published a booklet (GEA-6096) entitled "Clean Water—and How to Get It," designed to supply information on the urgency of providing proper sewage treatment and how to get it.

Another new G.E. bulletin (GEA-6180) describes the new "B" case Speed Variator power unit, a packaged, all-electric adjustable voltage d.c. drive operating from a.c.

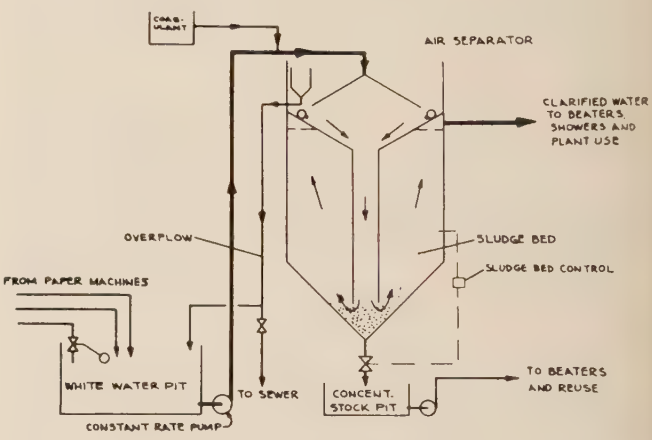
HUYCKFELT

Dan B. Wicker has been appointed assistant director of research, in charge of physical research, for F. C. Huyck & Sons, Rensselaer, N. Y.

Huyck has published a booklet describing the company and introducing some of the people who comprise it.

GRAVER

Graver Water Conditioning Co., New York, N. Y., is offering a white water reclaimer without moving parts, claimed to yield an effluent containing 0.25 to 0.50 lb. solids per 1000 gal.



Simple Graver solids-contact white water reclaimer

NATIONAL STARCH

The National Adhesives division of National Starch Products, Inc., 270 Madison Ave., New York, N. Y., is offering a new resin adhesive, Resyn 60R-3132, that is alkali-soluble and thus promises to eliminate the "gunk" formed in deinking waste papers contaminated with alkali-insoluble resin adhesive.

National has purchased land at Meredosia, Ill., for the construction of a second vinyl resin plant.

CARPENTER STEEL

C. Donald Steinwedel has been appointed assistant mill superintendent of the Union, N. J., mill of the Alloy Tube Division of the Carpenter Steel Co. Thomas J. Brennan has been transferred to the company's Charlotte, N. C., office, and George A. Davis has been assigned to the Houston, Tex., area. Arvin W. Harrington has been assigned to the New England district in addition to his present New York territory.

KIDDER

The Kidder Press Co., Dover, N. H., has appointed the Gibbs-Brower Co., New York, N. Y., its sales representative for Kidder slitters and rewinders to paper mills and converters throughout the United States and Canada east of the Rocky Mountains.

H. F. Hedbert, Albany Felt Co.

Carl Hendricks, Albany Felt Co.

Research-Cottrell

Engineering, manufacturing, and sales of Cottrell precipitators have been taken over by Research-Cottrell, Inc., a new wholly owned subsidiary of Research Corp., Bound Brook, N. J. The new firm has the following officers:

Manufacturing plant and executive offices, Research-Cottrell, Inc., Bound Brook, N. J.

Joseph W. Barker, chairman, Howard Coonley, vice-chairman, Carl Hedberg, president, L. M. Roberts, vice-president, P. F. Eilenberger, vice-president, James M. Knox, treasurer, and J. Wm. Hinkley, secretary.

Armstrong

Armstrong Machine Works, Three Rivers, Mich., has published a bulletin (No. 2022) describing the methods of selecting and installing Armstrong air traps.

Sandusky

Sandusky Foundry and Machine Co., Sandusky, Ohio, has issued two folders describing their recently expanded range of products and current metallurgical specifications for those products.

Ipex

The Tenth International Printing Machinery and Allied Trades Exhibition will be held at Olympia (London), England, July 5–16, 1955. Hundreds of machines, ranging from giant presses to those of the smallest jobbing printers, will be shown in operation under production conditions at the exhibition, which will cover nearly the entire 500,000 sq. ft. available at Olympia.

Foxboro

The Foxboro Co., Foxboro, Mass., has issued an application engineering data sheet (AED 823-13) describing a dew point control system claimed to cut down fireside deposits on boiler tubes.

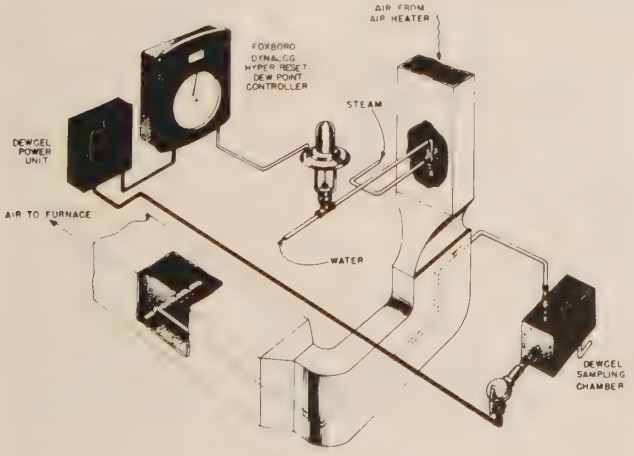
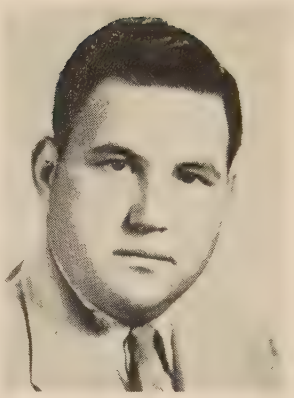


Diagram illustrates the type of humidification system which has reduced the rate of deposit formation on stoker-fired furnaces at Detroit Edison Co.

C. W. Hedberg, Research-Cottrell, Inc.



M. A. Minnig, Witco Chemical Co.

Witco

Max A. Minnig has been appointed executive vice-president of Witco Chemical Co., 260 Madison Ave., New York, N. Y.

B & W

Nicholas C. Jessen has been appointed assistant superintendent of the Barberton, Ohio, works of the Babcock & Wilcox's Boiler Division.

B. & W.'s Tubular Products Division, Beaver Falls, Pa., has published a bulletin (TB 356) giving information on its line of stainless steel piping, and a folder (TDC 162) on the welding of stainless steel tubular products.

Nopco

The following individuals have been added to the plastics sales staff of the Nopco Chemical Co., Harrison, N. J.: Edward L. Trabold, Robert LeWitter, Paul C. Luscusk, and Walter J. Major.

Plant Maintenance Conference

Thirty-seven sessions have been arranged for the Plant Maintenance and Engineering Conference to be held at the International Amphitheatre, Chicago, Ill., Jan. 24–26, 1955. The conference is held concurrently with the Plant Maintenance & Engineering Show, and conference sessions are scheduled so as to permit delegates to attend the show.

Black-Clawson

The world's largest 7-ply laminator at the Upson Co., Lockport, N. Y., has been completely revamped and modernized. The project was engineered by Dilts Machine Works, division of the Black-Clawson Co.

Minerals & Chemicals

Minerals & Chemicals Corp. of America is operating a new spray drying process at its plant in McIntyre, Ga., for purifying kaolin mined at the company's Klondyke mine six miles west of McIntyre.

At the Klondyke mine at the present time, stripping operations are removing approximately 95 ft. of overburden. The kaolin bed thus exposed is approximately 20 to 30 ft. thick. Between stripping and mining, something over 1,000,000 tons are moved every year at this mine.

The operations are carried on by means of 30-ton twin-engined Euclid scrapers which strip, overburden, mine, clay, and transport the mined material to the milling shed. The mined kaolin is deposited around the milling shed by the Euclids. It is then picked up by small Payloaders and dumped into a mill where water is added and a slurry is formed.

After primary degritting on a scalping screen, the slurry flows into a thickener tank and is then pumped 5 miles to the

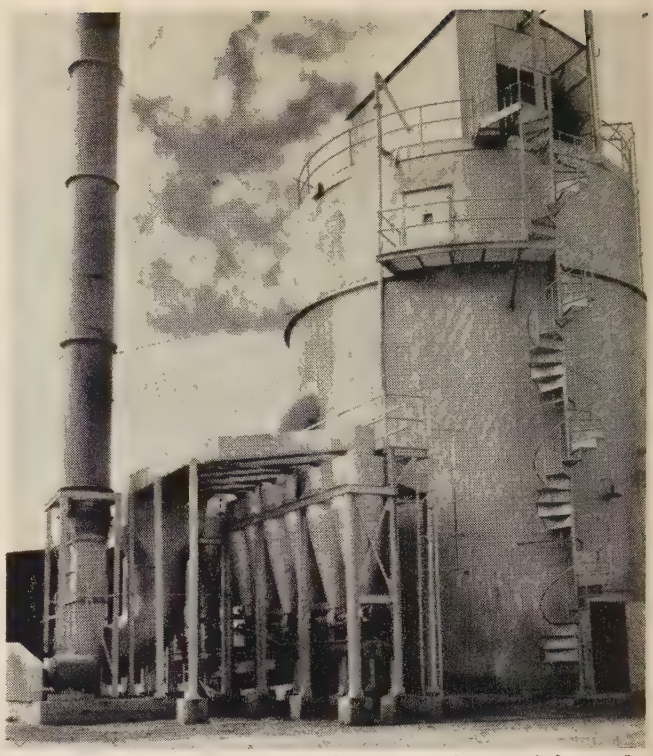
McIntyre plant. It is received in a thickener, and after the addition of a dispersant is put through a two-stage degritting process at 25–30% solids.

The basic kaolin particle is a hexagonal platelike crystal varying in size from under 0.5 to 44 microns. It also occurs in books or stacked up crystals. Classification separates the various crystal sizes without crushing or breaking the basic crystals.

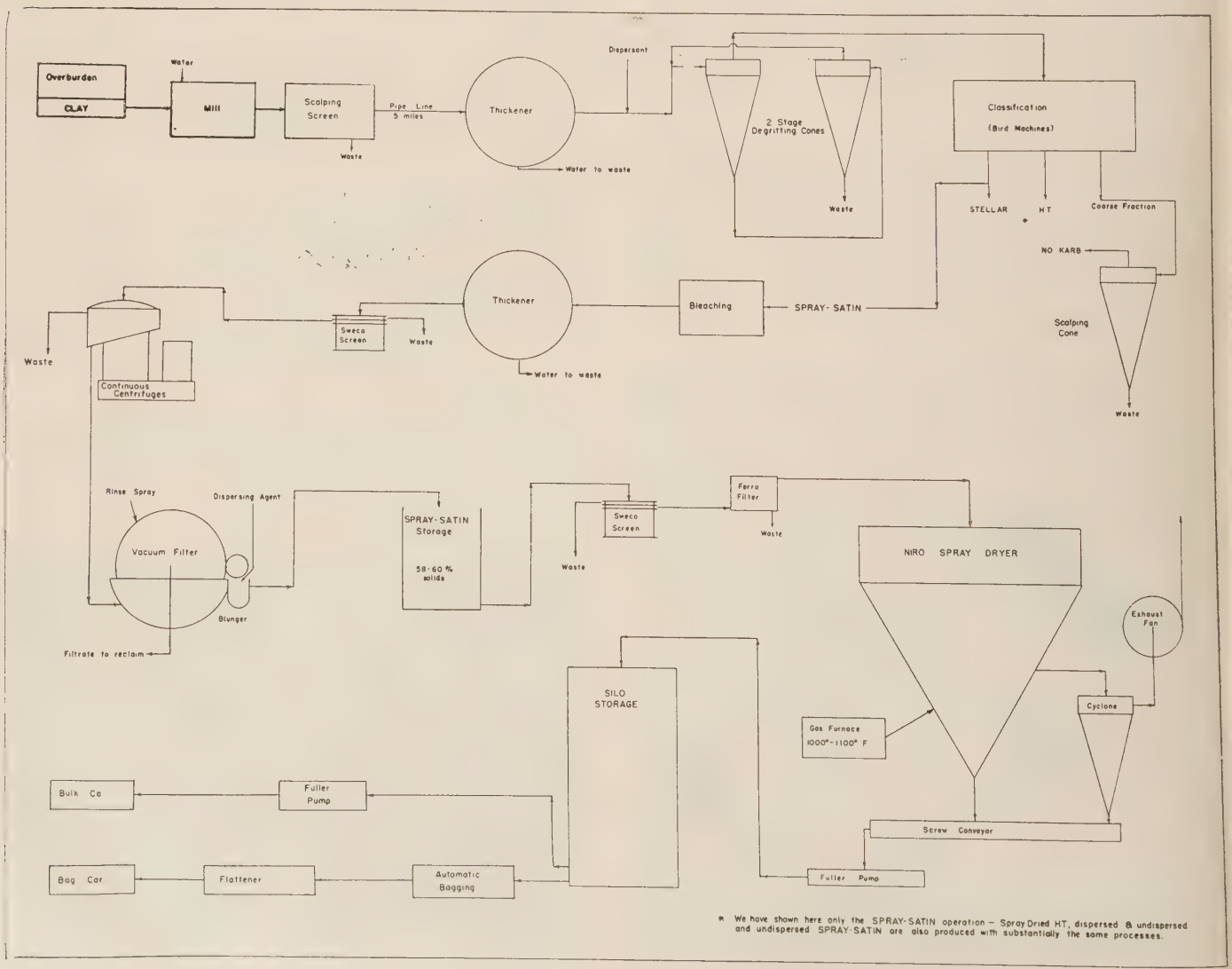
The raw material for spray drying is bleached in slurry form, thickened, and washed on a Sweco vibrating screen, then further thickened in dewatering centrifuges and finally on rotary vacuum filters where the kaolin cake is brought to 58–60% solids and further washed. A doctor roll of special design removes the cake, which is shaved by a doctor blade and deposited in a blunger where it is converted to a 58–60% solids slurry with the addition of tetrasodium pyrophosphate. After further cleaning on a Sweco screen and a liquid magnetic filter, the slurry is ready for spray drying.

The drier is a conical chamber into which air at 1000 to 1100°F. is continuously blown while the slurry enters through a nozzle and hits a special 10,000 r.p.m. impeller which produces a fine umbrella type spray. The particles are dried instantly to free-flowing globules. The exhaust air is put through cyclones to recover entrained particles. Fuller Airveyor systems transport the finished product to storage silos and thence to hopper and box cars. The product may also be gravity-fed to an automatic bag packer.

The most important features of the new process are the successful building up of a high solids cake of fine particle



Bank of cyclone scrubbers where air exhausted from the drying chamber is scrubbed to remove stray kaolin particles which are exhausted with the air

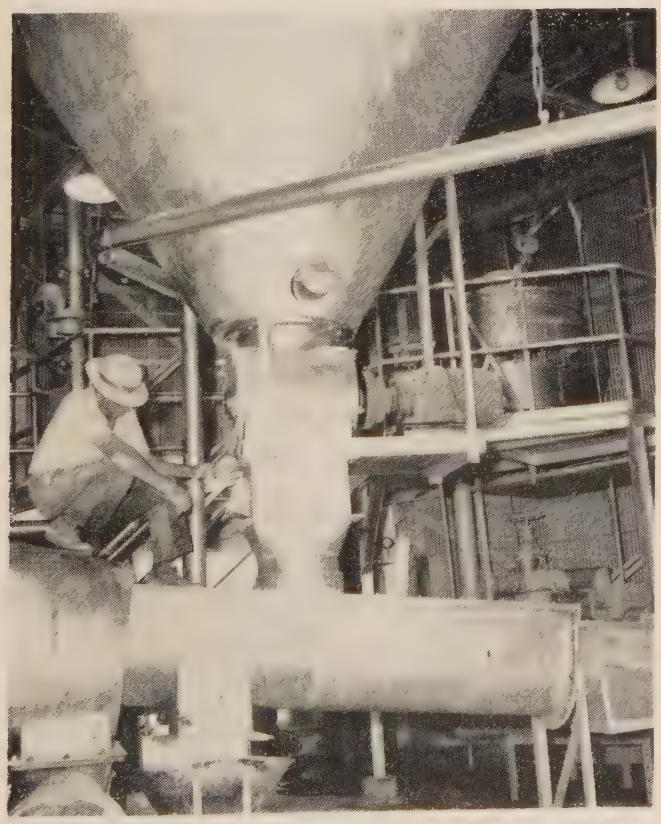


* We have shown here only the SPRAY-SATIN operation – Spray Dried HT, dispersed & undispersed and undispersed SPRAY-SATIN are also produced with substantially the same processes.

View of interior of milling shed where mined kaolin is deposited by Euclids. Small scoop-equipped Payloaders then move kaolin to the milling vat

size material and producing a free-flowing slurry at 60% solids. Spray drying has long been known to produce a superior product, but was slow and costly when performed on a 25–30% slurry. The new process is economical and yields a high bulk density product with only 0.0003% residue on a 325-mesh screen and a moisture content of under 1% without overdrying.

The trade name of the new product is Spray-Satin. It is claimed to give a coating of unusually high brightness and opacity. Being predispersed, Spray-Satin goes into suspension immediately, thus appreciably reducing make-down time.



Funnel shaped bottom of spray drying chamber where absolutely dry globules of Spray-Satin fall and are fed by screw conveyor into Fuller pumps to silo storage for airveying

STALEY

Thomas C. Garren has been appointed assistant to the director of technical service by the A. E. Staley Mfg. Co., Decatur, Ill.

RAYBESTOS-MANHATTAN

Manhattan Rubber Division, Raybestos-Manhattan, Inc., Passaic, N. J., has appointed Howell-Lanier Engineering Sales, Baltimore, Md., as metropolitan Baltimore distributors for Manhattan industrial rubber products.

HUBINGER

A typical example of free enterprise operating in the American economy, the Hubinger Co., Keokuk, Iowa, had its origin 73 years ago when J. C. Hubinger, a New Haven, Conn., broom maker, traded a dozen brooms for a laundry starch recipe. Hubinger's Elastic Starch became so popular that by 1900 he decided to start his own corn refining plant to insure an adequate supply of raw corn starch.

Destroyed by fire in 1903, the new plant was promptly rebuilt. The company now employs more than 500 people in its plant, offices, and laboratories, and produces a complete line of products from corn. Its latest addition is the new Hubinger Laboratory, completed in August of this year.

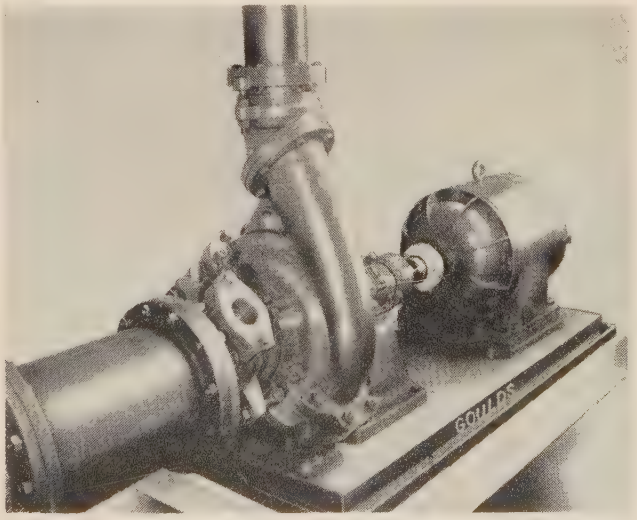
Built entirely of fireproof construction, the new laboratory is roughly 101 by 36 ft., and has three floors which house a general control laboratory, library, laboratory offices, pilot plant, sample room, engineering and personnel departments.

E. D. JONES

E. D. Jones & Sons Co., Pittsfield, Mass., has made a two-way manufacturing and sales agreement with Alexander Fleck Ltd., Ottawa, Ont. Jones will manufacture and/or sell Fleck equipment in the United States and Fleck will do the same for Jones equipment in Canada. Fleck is no longer representing the Black-Clawson Co. in Canada.

GOULDS

Goulds Pumps, Inc., Seneca Falls, N. Y., are offering a new line of paper stock pumps, designated Fig. 3135, which have radical new features designed for easy maintenance, including a diagonal-split casing, telescopic joint in the discharge connection, vertical discharge at the highest point in the casing, and suction and discharge on the same vertical centerline so that there is no need for right- and left-hand pumps.



The new Goulds Fig. 3135 paper stock pump. Note the telescopic joint in the discharge connection, and the hinged upper half casing

A-C

Allis-Chalmers Mfg. Co., 828 S. 70th St., Milwaukee, Wis., has published a leaflet (51 R 8195) describing what is believed to be the first rib-type enclosed, fan-cooled, wound-rotor motor to be made with slip rings, brushing rigging, rotor, and stator inside a single frame enclosure.

A-C has issued a booklet describing the company's West Allis works.

Robertson Electric Co., 126 S. Elmwood Ave., Buffalo, N. Y., has been named a distributor for A-C pumps in Erie and Niagara counties of New York; The Carleton Stuart Corp., 237 W. 54th St., New York, N. Y., pump distributor in Kings, Queens, Bronx, Westchester, Nassau, Suffolk, Richmond, and New York counties in New York; and the Vinson-Carter Electric Co., 325 N. Fourth St., Phoenix, control equipment distributor for Arizona.

Downingtown

Downingtown Mfg. Co., Downingtown, Pa., has issued a bulletin (no. 1150 A) describing Downingtown driers, frames, and rope carriers.

Downingtown has acquired the assets of the Monarch Forge & Machine Works, Portland, Ore.

Minneapolis-Honeywell

Marshall B. Taft has been named general manager of the valve division of Minneapolis-Honeywell Regulator Co., succeeding Stephen A. Keller, who has been named general manager of the new Heiland division of the company in Denver, Colo.

Container Labs

Container Laboratories, Inc., Chicago, Ill., has developed an instrument to measure the pliability of wrapping materials.

J-M

Johns-Manville, 22 E. 40th St., New York, N. Y., has issued a new edition of its brochure, "Good Operating Practices," containing 101 suggestions for maintaining plant buildings and equipment.

Oliver

Ward H. Pitkin has been appointed general sales manager of Oliver United Filters, Inc., New York, N. Y. Richard E. Bodette, Pittsfield, Mass., has been named sales engineer for Oliver, principally in New England and New York.

Cyanamid

James R. Wellman has been appointed director of American Cyanamid Co.'s new paper chemicals application laboratory in Chicago.

W. H. Pitkin, Oliver United Filters, Inc.

J. R. Wellman, American Cyanamid Co.

F & P

Fisher & Porter Co., Hatboro, Pa., has issued a new general catalog giving basic specifications of the company's complete line of process instrumentation.

Paisley

Paisley Products, Inc., division of Morningstar, Nicol, Inc., 630 W. 51st St., New York, N. Y., is offering a new envelope adhesive, Res-N-Seal, claimed to be absolutely noncurling.

Moore & White

Moore & White Co., Philadelphia, Pa., has contracted with H. W. Butterworth & Sons Co., Bethayres, Pa., for the manufacture of an extended line of paper and paperboard mill machines. One of the company's new products is an easily demountable split blade for slitting web materials.

Rice Barton

Rice Barton Corp., Worcester, Mass., has published a bulletin (No. SB9) describing the Spirolwrap, its new roll wrapping machine.

OBITUARY

Henry Kreitzer Benson

Henry K. Benson, professor emeritus of chemistry at the University of Washington, died on Sept. 27, 1954, in a Seattle, Wash. hospital following a long illness.

Dr. Benson was born in Lebanon, Pa., on Jan. 3, 1877, and received his PH.D. from Columbia University in 1907.

He became an assistant professor in the University of Washington Chemistry Department in 1904 and became head of the department in 1920. During the first World War he served as captain of the nitrogen fixation division of the Army Ordnance Department and later became chairman of the Division of Chemistry and Chemistry Technology of the National Research Council in Washington, D. C.

In 1926 an honorary doctor of science degree was bestowed upon him by Franklin & Marshall College in Lancaster, Pa. Dr. Benson was one of the organizers of the American Institute of Chemical Engineers and was instrumental in bringing about the organization of the Pacific Section of the Technical Association of the Pulp and Paper Industry.

He is survived by his wife, Eva Ronald; two sons, W. Ronald in Seattle and Col. Henry K. Benson in Tokyo; two daughters, Mrs. Harold J. Runstad of Seattle and Mrs. A. U. Martin of Los Angeles, and eight grandchildren.

Thomas H. Kiely

Thomas H. Kiely (father of Miss Helen U. Kiely, formerly chief chemist of the American Writing Paper Co., Holyoke, Mass.) died at his home in Northampton, Mass., on November 6.

Mr. Kiely was a prominent contractor and a partner in the firm of Kiely & Gleason. He was born in Northampton on Sept. 17, 1862, and resided in Northampton all his life.

He is survived by two daughters, Miss Helen U. Kiely and Mrs. Alfred Cosby, and two sons, James B. Kiely and William H. Kiely, a sister, Miss Minnie Kiely, a granddaughter, and several nieces and nephews.

Many individuals in the paper and allied industries were acquainted with Mr. Kiely and Helen.

Packaging Materials Testing Committee

The Joint TAPPI-PI Packaging Materials Testing Committee met at 2:30 p.m. on October 27 at the Roosevelt Hotel in New York. Eight committee members were present from a membership list of 22, and the total attendance was 13.

Discussion of Projects

(a) No. 277—Water Vapor Permeability of Sheet Material at 0°F., T 482 m-52. The present method seems to be satisfactory. This project is inactive at the present time.

(b) No. 387—Water Vapor Permeability at 100°F. and 90% Relative Humidity, T 464 m-45. T. E. Dobbins, subcommittee chairman, reported that a draft of the revision of this method had been prepared and reviewed by members of the subcommittee. There are now about 200 General Foods 24C cabinets in use and the revised method will specify this equipment. It will also specify in detail the exact procedure to be used. Five of the six members of the subcommittee were present at this meeting, and there was a thorough discussion of many of the details of the procedure.

Mr. Dobbins will prepare another draft of the revised method, incorporating changes agreed upon at this meeting. The revised procedure will then be used in a round-robin test on five water vapor barriers of different transmission rates.

(c) Creasing of Sheet Material for Water Vapor Permeability, T 465 sm-52. Charles Southwick, subcommittee chairman, reported that tests are under way in which the present creasing method is being compared to a dynamic creasing method. The results will be reported at the February meeting of the committee.

(d) No. 357—Water Vapor Permeability of Completed Packages Under Constant Conditions of Humidity and Temperature. C. M. Woodcock, subcommittee chairman, could not be present; however, he sent drafts of methods for measuring the water vapor permeability of packages using both calcium chloride and a product. These will be submitted to the membership of the committee for vote in the near future.

(e) Odor of Packaging Materials, T 483 sm-53. This project is inactive at the present time.

(f) No. 328—Odor Transfer Through Packaging Materials (organoleptic method). The method submitted at the February meeting has been circulated to the committee for vote. Eighteen committee members returned the ballot with seventeen voting yes and one voting no. Several minor changes were suggested when the ballots were returned. These have been incorporated into a draft of the method which is now ready for submittal as a suggested method. A. H. Landrock, subcommittee chairman, could not be present at this meeting but sent the final draft of the method.

(g) No. 388—Insect Resistance. H. S. Gardner, subcommittee chairman, was not present, and there was no report on this project.

(h) Gas Permeability of Sheet Material. A. H. Landrock, subcommittee chairman, was not present and there was no report on this project.

(i) No. 331—Heat Sealability. At the February meeting of the committee it was agreed that this project should be activated. The project was discussed in more detail at the April meeting of the committee. This project can be activated when someone agrees to become chairman of a subcommittee on this project.

(j) Water Vapor Permeability of Completed Packages Under Varying Degrees of Temperature and Relative Humidity. This project was discussed at the April meeting of the committee. It was felt by those present that there is so little known of cycling tests that it would be difficult to arrive at a standard test at this time. It was decided that for the present this project should be carried as inactive. If someone is interested in taking on the job of checking into this problem, we can certainly place it back on the active list.

(k) Rough Handling of Completed Packages. At the February meeting of the committee it was decided that rough handling of completed packages should be set up as a test method rather than be included as a part of the method on water vapor permeability of completed packages. The desirability of establishing rough handling test methods was also expressed at the April meeting of the committee. We need a volunteer to become chairman of the subcommittee on this project.

Plans for Future Committee Meetings

A committee meeting will be held at the Commodore Hotel, New York, N.Y., at 10:00 a.m. on Monday, Feb. 21, 1955. Reports will be made by chairmen of all subcommittees, and all projects will be discussed at this meeting.

Howard Gardner is arranging for a group of papers to be given at the February meeting on the subject of insect resistance.

Membership

Present membership of the committee is as follows:

Wm. H. Aiken, Gardner Board and Carton Co., Middletown, Ohio.
Phillip S. Barnhart, 20 Craigwell Ave., West Springfield, Mass.
L. F. Borchardt, General Mills, Inc., Minneapolis 13, Minn.
J. d'A. Clark, Longview, Wash.
T. E. Dobbins, American Can Co., Maywood, Ill.
Howard S. Gardner, Fibreboard Products, Inc., Antioch, Calif.
C. N. Hagar, Jr., The Diamond Match Co., Plattsburg, N. Y.
Walter L. Hardy, Foster D. Snell, Inc., New York 11, N. Y.
T. A. Howells, Institute of Paper Chemistry, Appleton, Wis.
C. E. Hrubesky, Forest Products Laboratory, Madison 5, Wis.
A. H. Landrock, Olin Industries, Inc., New Haven 4, Conn.
C. C. Lavers, Maple Leaf Milling Co., Toronto 9, Ont.
Peter J. Metz, Crown Zellerbach Corp., San Leandro, Calif.
R. T. Nazzaro, Westfield River Paper Co., Russell, Mass.
George W. Renninger, American Viscose Corp., Fredericksburg, Va.
J. J. Schwenkler, Container Corp. of America, Philadelphia 27, Pa.
L. E. Simerl, Olin Industries, Inc., New Haven 4, Conn.
C. A. Southwick, Jr., Hope, N. J.
W. M. Van Horn, Institute of Paper Chemistry, Appleton, Wis.
P. K. Wolper, Riegel Paper Corp., Milford, N. J.
C. M. Woodcock, General Foods Corp., Hoboken, N. J.
Milton Yezek, General Foods Corp., Battle Creek, Mich.

Water Vapor Permeability Subcommittee

T. E. Dobbins, *Chairman*
Philip S. Barnhart
L. E. Simerl
C. A. Southwick
P. K. Wolper
C. M. Woodcock

W. V. P. Completed Packages Subcommittee

C. M. Woodcock, *Chairman* L. F. Borchardt

Insect Resistance of Packages, Paper, and Paperboard Subcommittee

H. S. Gardner, *Chairman*

A. H. Landrock W. M. Van Horn

Flavor and Odor Transfer Subcommittee

A. H. Landrock, *Chairman*

Walter L. Hardy C. C. Lavers

Creasing of Sheet Material for Water Vapor Permeability Test Committee

C. A. Southwick, *Chairman*

Gas Permeability of Sheet Material Subcommittee

A. H. Landrock, *Chairman*

Walter L. Hardy C. M. Woodcock

W. H. Aiken, *Chairman*

LETTERS TO THE EDITOR

Slimicides

To the Editor, *Tappi:*

I wish to evaluate the various products used as slime inhibitors in the manufacture of paper. Please let me know the methods used by large pulp and paper manufacturers.

M. Bergman
Toronto, Ont.

To the Editor, *Tappi:*

At present, the pulp and paper industry has not officially approved any specific method for the evaluation of potential slime control agents. There are many different methods which may be used to evaluate various slime control agents in the laboratory. The programs carried out at The Institute of Paper Chemistry for the American Pulp and Paper Association has as one of its facets of activity a program of evaluating various slime control agents. This laboratory procedure is easy to use and requires a minimum of bacteriological training and technique. The method is rapid and gives an excellent index of the potentiality of the material under test. I suggest that Mr. Bergman use this procedure so that he can check his results with these already obtained and published under the APPA program.

The above method is adequately described in the following article: Shema, B. F., and Conkey, Julian H., "The Relative Toxicity of Disinfectants Available for Use in the Pulp and Paper Industry," *Tappi* 36, No. 11: 20A, 24A, 26A, 28A and 30A (Nov., 1953).

B. F. Shema, *Chief Microbiologist*
W. H. & L. D. Betz, Philadelphia, Pa.

Filter Paper Control Standard for Varnishes

To the Editor, *Tappi:*

I would appreciate your help and advice in selecting and locating a paper to be used as a control standard in measuring the penetration of our phenolic and melamine varnishes. We have found that the common tests on varnishes are inadequate for predicting the penetrating or saturating qualities of a varnish. I presume that someone makes especially carefully controlled papers intended for determining this property of varnishes. If so would you please refer me to a supplier? If not, I'd still appreciate any recommendations you can make on choosing a standard paper for such a test.

D. E. Baldwin, *Engineering Supervisor*
Plywood-Plastics Corp., Hampton, S. C.

To the Editor, *Tappi:*

The Subcommittee on Fibrous Materials for Laminated Products of the TAPPI Plastics Committee has for one of its immediate projects the very thing that Mr. Baldwin mentions in his communication. In other words, the subcommittee is presently working on standard methods explicitly for the prediction of penetration values of resin varnishes. The minutes of the last meeting will indicate that at the beginning we would use a Whatman filter paper no. 5 as our standard sheet for the comparative evaluation of varnishes. However, it may be that the members of the subcommittee have since changed their minds and have come up with other recommendations.

R. T. Nazzaro, *Chairman*
TAPPI Plastics Committee

Bacteria Varieties

To the Editor, *Tappi:*

While making investigation on the slime control in our sulphate pulp and paper mill on the basis of literature published by TAPPI, I am unable to identify the various varieties of bacteria in the raw water system and in the slime at different stages of process.

I shall feel obliged if you would arrange to send me standard literature and books together with a detailed atlas of microphotographs of these bacteria that may be available in your country for identification and control.

K. N. Tenany
Orient Paper Mills Ltd.
Brajrajnagar, India

To the Editor, *Tappi:*

Appended hereto is a list of references which I have asked Mr. Appling and Mr. Sharpley to assemble to go to you with this letter. Frankly, I doubt that Mr. Tenany adequately understands the work on which he is embarking. He apparently is thinking in terms of identifying bacteria primarily from morphology alone. As you know, physiological tests are an important part of the identification of bacteria. "Bergey's Manual" would be a good one for him to consult for bacteria. However, a number of books would be necessary to do a reasonable job on fungi.

"An Introduction to Industrial Mycology," by George Smith (Edward Arnold and Co., Ltd., 41 Maddox St., London W1).
"Introductory Mycology," by C. J. Alexopoulos (John Wiley and Sons, Inc., 440 Fourth Ave., New York 16).
"Manual of the Penicillia," by K. B. Raper and Charles Thom (The Williams and Wilkins Co., Mt. Royal and Guilford Aves., Baltimore 2).
"Manual of the Aspergilli," by Charles Thom and K. B. Raper (The Williams and Wilkins Co.).
"Morphology and Taxonomy of Fungi," by E. A. Bessey (The Blakiston Co., Inc., 1012 Walnut St., Philadelphia 5).
"Bergey's Manual of Determinative Bacteriology," by R. S. Breed, E. G. D. Murray, and A. Parker Hitchens (The Williams and Wilkins Co.).

S. J. Buckman, *President*
Buckman Laboratories, Inc.
Memphis, Tenn.

40th Annual Meeting
TAPPI
February 21–24, 1955

LOCAL SECTION ACTIVITIES

Reports of Meetings, Personnel, and Events

New England

A joint meeting of the New England Section of TAPPI and the Connecticut Valley Superintendents' Assoc. was held on Oct. 8 and 9, 1954, at the Berkshire Inn, Great Barrington, Mass. About 200 people attended both meetings and dinner.

Mill visits to Crane & Co., Bay State mill, Dalton, Mass., were held on Friday morning, October 8.

A. F. Kirkpatrick of the Research Div. of American Cyanamid Co., Stamford. Conn., discussed "Let's Look and See—Some Applications of Microscopy to the Paper Industry"; and John Bainbridge of the Monsanto Chemical Co., St. Louis, Mo., talked on "The Properties and Commercial Use of Papermakers Alum." A lively discussion period followed these talks.

Travel movies were also shown, courtesy of the Cunard Steamship Lines and Transcontinental Western Airways.

Because of company clearance required for their papers by the two speakers, neither of the papers is yet available for publication. However, it is expected that it will be possible to publish them in a later issue of *Tappi*.

R. W. Ramsdell, *Secretary-Treasurer*

Lake Erie

The second meeting of the Lake Erie Section was held at the Hotel Carter on Friday evening, Oct. 8, 1954.

There were 44 members and guests present for dinner and the meeting. The subject for the meeting was "Board versus Lightweight Kraft as It Affects Material Suppliers." This was a panel-type meeting with Ben Beau of National Container Corp. as moderator.

Ted Wells of Moser Bag & Paper Co. spoke on the subject "Flexible Packagings Needs"; C. P. Spring of National Container Corp. spoke on the subject "Flexible Containers' Needs"; Douglas Adams of Canton Corrugated spoke on the subject "Board Converter's Needs"; Charles Markee of Ohio Boxboard Co., spoke on the subject "Board Producer's Knowledge of Converter's Requirements"; Al Daniels of Chase Bag Co. spoke on the subject "Lightweight Producer's Knowledge of Converter's Requirements."

Each speaker spoke for 5 minutes. When all speakers were finished there were questions from the floor.

The papers presented by Messrs. Wells, Spring, and Markee follow this report.

John F. Richmond, *Secretary*

Board Producer's Knowledge of Converters' Requirements

Charles Markee

It is extremely gratifying to see a program of this type presented by our group. Most of us are inclined to feel that our own problems and requirements are so paramount that we cannot find the time to worry about the other fellow's difficulties. Actually, if we knew a little more about these difficulties we often find that the two are very closely related and that by considering them together the ultimate solution to both is much more obvious. This solution may be nothing more than a clear-cut specification or statement from the board or paper purchaser outlining for just what the material will be used.

I know this may sound like the type of thing everyone asks for as a matter of course. However, it is surprising how often such a simple thing as this is neglected and can cause both the supplier and purchaser a lot of grief.

As an example, let me tell you of an incident that happened not too long ago to a major board producer. This producer (not OBB incidentally) makes a special high-grade sheet which sells for a substantial premium over regular grades. Having an alert sales force, they acquired a new customer who requested this special sheet. Because of the price mark-up the company did not charge any premium for a sheet treated for printing gloss inks and thought nothing of it when the customer specified this treatment. Shortly after delivery of the initial order, a complaint came from the customer that the board was no good. It wouldn't print worth a darn. This naturally caused quite a furor at the company and after exhaustive checks disclosed nothing out of the way. They finally sent the super to the customer's plant to look into it. The first thing the super saw was his printed board and there was no doubt but what it was a pretty sad printing job. However, the reason it was so bad was that the customer was printing a flat ink job on this board that had been specially treated to hold ink on the surface and give gloss. Evidently, the converter figured that as long as gloss ink treated board didn't cost any more than regular board, he was going to take it and get that little something extra for nothing.

Now how does that little incident relate to the business at hand? Well, I feel that it is a good example of the types of troubles that can occur if the complete story concerning end uses and board characteristics is not known. What is good in one particular instance is not necessarily going to do the job in another.

Good printability, for example, requires a board that has good formation, uniform caliper and density, good finish, and the correct, uniform level of ink receptivity for the job at hand. If the board is to be printed on letterpress equipment, we should add compressibility to this list. With a sheet of uniform caliper and density and the correct degree of compressibility, a certain amount of finish may be sacrificed and still obtain a satisfactory printing job by this method. If, on the other hand, the printing operation is to be done on printer-slotter equipment, board compressibility will not help to any significant degree since printing pressures are necessarily kept to a minimum. Here good finish is probably one of the more important features necessary in a board.

We all realize that the best piece of board made is absolutely useless to both the customer and ourselves if it cannot be glued properly in process. Therefore, it is extremely important that we consider this factor when we impart certain properties into the board. How many of you corrugator men have seen what appears to be the ideal corrugating medium from a strength and rigidity standpoint only to find that your adhesive would not penetrate properly to allow you to fabricate it economically?

As you can see, this business of making a sheet, whether it be board or paper, is really a series of compromises to obtain a material to fit a number of converting operations.

Charles Markee, Ohio Boxboard Co., Rittman, Ohio.

Probably the greatest compromise we must make is on the strength properties of the board. Unfortunately, optimum strength is not always conducive to this good formation and finish we talked about. On the other hand, a sheet that is to be scored and folded must have strength that comes from comparatively long fibers to withstand cracking. Moisture content of the board is also critical since too dry a sheet will tend to crack, while a wet sheet will be limp and hard to cut.

Strength and moisture content are also important characteristics of materials to be laminated. The web strength of the sheets, both board and paper, must be sufficient to prevent undue breaks in the operation, while the moisture content must be uniform to prevent warpage either at the end of the laminator or on subsequent storage.

It is difficult to say what particular property or combination of properties are necessary for a good converting operation on board. You can speak in generalities but when it comes right down to the final analysis, the specific job the board is expected to do will determine the sheet to make. I would like to emphasize again that a statement of the job to the board manufacturer will enable him to do a better job for you and for himself.

Flexible Containers' Needs

C. P. Spring

SEEN through the eyes of our suppliers, we who make multiwall shipping sacks would like to have the moon on a silver platter. We'll break down and admit it, because those fine people, our customers, ask for the same from us, and we pass the problems along the line.

We are asked to furnish flexible containers which will:

Pack rapidly on high-speed filling equipment;
Suffer phenomenally low breakage in the packing plant;
Hold hot or cold, wet or dry, dense or bulky, dust or lumpy products without failing in shipment;
Stack neatly to mountainous heights in a warehouse without falling over;
Resist acids, alkalies, grease, and oil;
Shield the product from rain, dirt, moisture, and loss by sifting;
Carry a brilliantly printed, smudge, and dirtproof brand for advertising value.

As with practically any phase of modern technology, one half of the required properties promptly line themselves up on one side of the problem and do a superb job of opposing the other half. We have to live with these constant battles among properties. We can resolve some of them, but not all; so we are anything but bashful about turning over to our suppliers those problems which can be mastered only by the paper, ink, and adhesive makers—often in teams.

Let's pick some of these problems apart and see what they mean to ourselves and our suppliers. It is one of the purposes of this meeting, I understand, for the board makers and converters to swap troubles and cures with us, so we will hope to learn something new from some of them when the discussions start.

Basis Weight. We buy paper by the pound and sell our bags by count, so we are faced with the problem of low yield from a given number of pounds of paper if the basis weight is higher than nominal. We also have to pay through the nose for in-freight and out-freight. And if we put extra heavy paper in the customer's bag, either it may fail to pack properly or we run the risk of getting the packer operator accustomed to a heavy bag, whereupon he will complain bitterly to us when we finally put the proper basis weight paper in the bag.

Strength. The physical test requirements for tearing resistance and tensile strength of multiwall shipping sack kraft have been set by the Freight Classification Committee of the railroads, and are based on long years of experience. Tensile strength must be high in the cross direction so the bags will not split up the middle when dropped. There must be plenty of long fibers in the sheet to provide flexibility. This is reflected by a high tearing resistance test in both directions.

Porosity. Here's another headache for the papermaker. He is bound to develop some denseness to the sheet in producing adequate tensile strength; however, he must not go too high with the densometer test or our customers may not be able to pack their product fast or accurately in our valve sacks—the kind which is closed on both ends but has one opening for the spout of the packing machine. The sheets comprising the bag must be porous enough to dissipate the air which is introduced along with the product being packed.

Sizing. Here's a triple-faced problem if ever there was one! The lightest weight multiwall kraft generally used (40 lb.) is thin and open in formation by comparison to heavier weights like 50 and 60 lb. The papermakers say it is harder to size, and they seem to like to use the same percentage of sizing in all weights. Sometimes this means that the heavier weights are sized very heavily, while the light 40-lb. is less sized. Then we use all three weights in one bag, and the single paste we use to glue the seam of each ply and to glue the plies together, may seep through the light paper (sticking the inner surfaces together) while failing to produce a strong seam on the heavy paper. There seems to be room for development and control work in all phases: papermaking, glue formulation, and bagmaking techniques.

Let's remember also that the degree of sizing of all weights of multiwall kraft must be fairly good so that bags left out overnight will not fail completely if a rain falls. In other words, the paper must be "showerproof."

Surface Finish. Right now let me put in my bid for the aspirin concession for this one! We have some opposing factors again.

First, the finish should be smooth enough to present a good printing surface for maximum ink coverage at lowest printing cost, coupled with rapid drying and infrequent printing plate cleanings. Smoothness is also desired for assuring that dirt will not mar the printed brand over fairly long periods of time. But before we go too far with smoothness, let it not be accomplished with excessive calendering, or the flexibility of the sheet may suffer.

Now we can turn around and recount the needs for rough finish. The dust from commodities like flour, starch, and animal feeds will act like ball bearings when dusty filled bags are stacked on pallets or in piles. The net result is slippage in the stacks, a hazardous and damaging factor. Some type of naturally rough or artificially roughened finish is needed; but again, there are limitations. Let it not be so rough that scuffing or rolling up of the paper surface occurs, or that physical tests suffer, or that ink need be flooded onto the bags to make a decent print job.

We have to see to it also that any special machine or secondary treatment does not become nullified by the dust it is intended to overcome, or that the filled bags with treated outer ply do not become jammed in the packer's warehouse chutes.

Many valiant attempts have been made by mills to produce a really rough yet strong and effective sheet: by chemical manufacturers to find a cohesive material, by ink makers to make a nonskid ink; but the final answer is not yet with us, and we hope it will be forthcoming soon.

Acidity-pH. Multiwall paper must be made at or near the neutral point, otherwise certain products which are packed hot will degrade the cellulose and weaken the bag. The burden is on the papermaker to curtail the use of acid and/or alum to provide a pH no lower than 6.5 when determined by hot extraction.

Moisture. Here is a vital factor in bagmaking and bag

C. P. SPRING, National Container Corp., Clyattville, Ga.

performance. Paper with a moisture content of 6 or 7% is flexible and works well on the bag tubing machines. Let us get dry paper, and we lose production rapidly.

It is an important factor in nesting, also. By this we mean the snug fit of each successive ply within the next one, since dry paper will expand when dampened and moist paper will shrink when moisture is lost. If a sheet of each is included in a bag which is nested perfectly on the machine, the moistures will equalize, the dimensions will change, and the good nesting is lost. We need, therefore, to have our supplies of paper come in with uniform moisture content of about 6 to 7%.

There are some of our requirements. Your comments will be welcome.

Flexible Packaging Needs

T. W. Wells

PERHAPS the only reason that a member of the Moser Bag & Paper Co. stands before you today to tell you what his company now asks for in the way of paper is this Lake Erie Section of TAPPI in itself. For if it were not for the associations and contacts that we at Moser have made during the past few years here, we would have never realized the great importance that the specifications in paper made as far as good production in our plant is concerned. Previous to our looking into the technical aspects of paper, whenever we had poor production in the plant we were not always sure whether it was the man, the machine, or the paper itself. Consequently this led to a great deal of friction between production and management in our plant because we had no solid ground on which to base our accusations, or any clear-cut way of eliminating the paper as a source of trouble.

One other thing I might explain, as far as specifications are concerned, we are rather limited in what we can ask for because of the nature of our business. We are manufacturers of garment, millinery, notion, and bread bags from a 30-lb. basis sheet. Most kraft paper mills as you so well know, cater to their large volume customers, namely the multiwall sack people. We realize that while our class of bag comprises but 5 to 10% of the total tonnage of most kraft mills, we consequently cannot dictate exactly the kind of paper we want. As a matter of fact many mills when running a poor sheet of paper, by having pulp that is fouled up somewhere along the line between the chippers and the screen, usually run this into what is commonly called "garment bag paper."

However, of late we have found that many of our mills have become most cooperative in giving our specifications some consideration and consequently the quality of our paper has increased a good deal.

One of the things that is most important to us, as converters of paper into bags, is the condition of the roll of paper as it comes to us. If the sheet is too uneven, due to the hot spots in your nip rolls, we have a great deal of trouble drawing the paper over our machines because we run it over steel rollers. Any unevenness in the sheet usually results in an unusually high number of jam-ups for that machine. Of course to test this we make the same test that is usually given in the paper mills, of hitting the roll with a wooden stick to "sound it out." One other thing that is quite important in our line of business is the lap that the paper manufacturer puts into our rolls. Of course, it is very important to have all laps flagged, but if he puts in two strips of 60-lb. kraft tape to splice our roll we find we are throwing our machine completely out of whack when our striker bar usually accustomed to hitting two sheets of 30-lb. paper suddenly comes up against two sheets of 60-lb. It not only jams up our machines, but quite often throws the machine setting out of line.

As for basis weight, one of the fastest ways to eat up the small profit that is in the bag business these days, is to give us a couple of pounds more paper to the ream than we price our bags. In general, of course, we must take into consideration the limitations that you fellows have at the mill and the 1 lb. plus or minus will not hurt us.

The caliper of the sheet is important to us for two reasons. Our notion and millinery and garment bag customers like a bulky sheet. That is, something just a little bit better than 1 point per pound as it aids us quite a bit in selling our bags. It's the "feel" that the customers test many of our bags. Of course, many of our bread bag customers want a shiny sheet, and consequently, are willing to sacrifice the caliper of the paper to get this higher finish for printing. If the sheet is too bulky—of course we realize that it is impossible to control the evenness of the sheet at the mill—it gives us trouble. Tearing strength in multiwall sacks does have some bearing on our specifications. If a sheet is too weak and tears, we have a great deal of trouble in handling the web on our machines. However, our specifications for this tear are not as stringent as the heavier bats, because we are putting stockings, peanuts, or other light articles in most of our bags.

Tensile strength, on the other hand, is quite important to us as far as running characteristics on the machine are concerned. We find that we must have a machine direction tensile somewhere around 20. A cross direction tensile down as low as 8 will not hurt us too much in our running. However, if we get down in the neighborhood of 14 or 15 in the machine direction we really have a lot of trouble as it slows our machines down to almost half speed.

Brightness is something else that our customers govern. We find that we need from a 70 to an 80 brightness to satisfy most of our customers. We've had trouble before in getting a strong sheet with a high brightness, but with the changing of the bleaching processes of many mills to chlorine dioxide, we are assured that we will get a sheet of from 80 to 85 brightness that still has a good tensile and tear.

One combination of industries that we understand works quite closely as far as machine specifications are concerned is the Millprint-Nicolet group in Wisconsin. Apparently the paper mill and converting bag factory are across the street from each other. When they have trouble on bag machines, they can bring the mill man right into the bag factory to witness the plight of the bag machine operator.

Those are the gripes we have; that's the sheet we want, so you know what we at Moser will be requesting each time we put in a purchase order.

T. W. WELLS, Moser Bag & Paper Co., Cleveland, Ohio.

Empire State (Northern District)

The Northern District, Empire State Section, held its first meeting of the season Thursday, October 14, at the Hotel Woodruff in Watertown. Seventy-two members were present and enjoyed an informative program by eight members of the local section describing new developments of interest in various local mills. The speakers and their topics were as follows:

Thomas Meehan, assistant manager, Crown Zellerbach Corp., Carthage, N. Y., "General Description of Crown Zellerbach Mill"

Orville Munger, resident engineer, Crown Zellerbach Corp., Carthage, N. Y., "Description of Crown Zellerbach Deinking Plant"

Sheldon Young, technical supervisor, Crown Zellerbach Corp., Carthage, N. Y., chairman of the district, "Operation of Centri-Cleaners at Crown Zellerbach"

John C. Parsell, J. P. Lewis Co., Beaver Falls, N. Y., "Laminated Plastics"

Roger Schwarz, Knowlton Bros., Watertown, N. Y., chairman-elect of district, "Radioactivity Checks at Knowlton Brothers"

Wayne Morrow, paper mill supt., Newton Falls Paper Co., Newton Falls, N. Y., "Importance of Waste Paper as Paper Furnish"

Alfred Wagner, Newton Falls Paper Co., Newton Falls, N. Y., "Moisture Control"

Part of the group of the Eastern District of the Empire State Section at the Albany Felt Co.

James B. Sisson, chemist, St. Regis Paper Co., Carthage, N. Y.. "Polyethylene Coated Papers at Carthage"

ELIZABETH L. CASE, *Secretary*

Empire State (Eastern District)

This meeting was a mill visit to the plant of Albany Felt Co., followed by a social hour and dinner at Wolferts Roost Country Club, sponsored by Albany Felt Co.

The business meeting was called to order at 8:10 by the chairman, Grant Cole. Fred Somerville, chairman of the Section, was introduced and spoke on membership. The secretary gave a short summary of the organizational meeting of August 26. The treasurer reported a balance on hand of $196. Then followed reports by the various committee chairmen with Vince Long, program committee chairman, introducing James Smith of Albany Felt, who presented the program of the evening with color pictures, followed by talks on quality control and product design by Everett Reed and Henry McMillan, respectively. There was a short but in-

Another part of the group at Albany Felt Co. from the Eastern District, Empire State Section

teresting question and answer period in which Messrs. Smith, McMillan, and Reed were joined by Larry Woodside. The meeting adjourned at 10:00 p.m.

RICHARD J. COLLINS, *Secretary*

Empire State (Metropolitan District)

About 50 members and guests were present at the Oct. 19, 1954, dinner meeting of the Metropolitan District, Empire State Section of TAPPI, held at Fraunces Tavern in New York City.

Chairman John Rice of the Lowe Paper Co. announced that the district planned to start a series of annual plant visits to various paper mills, box plants, and printing plants in the New York City area. For the first visit a trip will be made to the paper mill and box plant of the Gibraltar Paper Co., Inc. in North Bergen, N. J., on Nov. 9, 1954.

The speaker for the evening was T. J. Gross, technical advisor to the Union Bag & Paper Corp., who spoke on "General Principles of Packaging." The talk was followed by an interesting discussion period. A copy of the talk follows.

L. E. GEORGEVITS, *Publicity Chairman*

General Principles of Packaging

T. J. Gross

ONE of the things that makes the fiber box industry different from most other industries is that it is a 100% custom business. Every corrugated box made today is specially built to do a particular job, and to meet a customer's particular needs and conditions. And it is rare indeed, that we find any two customers with exactly identical needs. Everybody has a different problem and everybody is looking for a different answer. That is why we have packaging engineers.

It is the packaging engineer's job to create a package which will provide protection in the degree needed and of the type needed to assure efficient and economical transportation of its contents. To do this job properly the packaging engineer must have a thorough acquaintance with the various factors which are considered when determining what type of container is needed to do a particular job. He should have a first-hand knowledge of the particular use requirements involved. He must know what shipping hazards the container is apt to encounter, and the effect those hazards may have on the contents of the container. And, of course, he must have a well-grounded understanding of the principles of protective packaging.

Now, I am not going to attempt to make packaging engineers out of you in one easy lesson, but I would like to give you in outline form some of the general principles of package design, so that you may have a better understanding of what is involved in the job.

First, let us list some of the considerations which must be made when a container is being selected for any given product. We will list these in order of their importance to the box user:

1. *Protection.* This is the first and most important consideration. It is the prime function of a container. Container must protect product or it is useless.

2. *Carrier Regulations.* Container must conform to rules of carriers otherwise it cannot be transported. The box must meet Rule 41 (or its exception) for rail shipment, Rule 18 for express, and Rule 5 for certain products shipped by motor carrier.

3. *Adaptability to Production Facilities.* Container must fit into presently available filling, closing, and handling equipment.

4. *Adaptability to Storage and Distribution Methods.* Container must be able to store satisfactorily under user's particular conditions—long storage or short storage, moist or dry, cold storage, etc. If warehouse is palletized, shape of box must be suitable for that purpose. Container must meet distribution methods—is it rehandled or reshipped? Does it have to be opened for inspection or removal of part of contents and then resealed?

These first four points might be called the primary considerations. We can list four more which we might call secondary considerations:

5. *Cost.* The cost should be the lowest possible without sacrifice of the primary considerations.

6. *Advertising Value and Display Features.* The container should have attractive appearance and, where desirable, be adaptable for display purposes.

7. *Re-use.* Where production and distribution methods permit, more than one use of the container is a big advantage, provided primary considerations are not adversely affected or increase in cost affects economy.

8. *Consumer Acceptance and Convenience.* The container must fit into use practices of box user's customer or ultimate consumer. Where accepted trade practices prevail as to quality, size, weight, etc., these should be adhered to as far as possible.

Now, let's look at some of the things that can happen to a container in its travels which might cause damage to its contents. What are some of the hazards to which the container is exposed and what effect might they have on the product inside the box?

1. *Impact or Shock.* The dropping or throwing of a container, humping or switching of freight cars, etc., can cause breakage or bending of product.

2. *Vibration.* This important cause of damage has only in recent years been recognized as such. Vibration can cause loosening of parts and actual breakage where vibration coincides with natural frequency of product and sets up harmonic resonance.

3. *Puncturing Blows.* The corner of another box, contact with any sharp object such as protruding nails in car walls, etc., can cause piercing, tearing, denting of product.

4. *Crushing.* Stacking in warehouse or in car or truck. Also shifting of load in transit causes crushing, distortion, breaking, and bending.

5. *Temperature Changes.* Movement from hot to cold climates or vice versa, into or out of cold storage, etc., can cause melting or freezing and consequent spoilage.

6. *Moisture.* High humidity conditions in storage or transit can cause rusting, corrosion, spoilage.

7. *Water.* Exposure to rain from outdoor storage, condensation as a result of removal from cold storage, shipment in leaking car or truck, etc., can cause staining, rusting, corrosion, spoilage.

8. *Scuffing.* Shifting in car or truck in transit, rubbing against rails or supports in conveyer system destroys the attractive appearance of the container and causes loss of advertising and display value.

9. *Contamination.* Dirt, cinders and foreign matter getting into the containers from shipment in uncleaned car or truck. Also penetration by odors and gases. Also, insect infestation due to unfavorable storage conditions, causes dirtying, spoilage of product.

10. *Pilferage.* Theft of whole package or portion of contents in storage or transit, causes loss of contents.

Now that we have counted and identified the enemy, let's take a look at what qualities or attributes the container must have to successfully combat these forces of destruction and protect its cargo. Some time ago a well-known packaging engineer prepared a list of 15 basic principles covering all aspects of package protection. I have modified the list slightly so that it will apply specifically to corrugated boxes. Here it is:

1. *Enclosure.* This is an obvious requirement. The

T. J. GROSS, Technical Adviser, Union Bag & Paper Corp., New York, N. Y.

container must act as a shield against contact with all outside bodies.

2. *Retention.* Container must be strong enough to retain its contents. For many types of products the container is more subject to damage by the contents than it is by outside objects. For example, scores of canned goods cases are frequently cut or ruptured by the action of the beads of the cans inside the case.

3. *Stability.* This is the principle which defines a rigid container. It differentiates a box from a bag. A rigid container such as a corrugated box, must be able to retain its shape when placed under stress.

4. *Restraint.* Fit of product in container. Product must not be free to move around in container except small amount required for cushioning (deceleration).

5. *Separation.* Multiple contents which can damage each other must be separated. For example, glass bottles are separated by use of partitions.

6. *Cushion.* Package must be able to dissipate shocks and blows through proper cushioning. This requires some slight movement of product but such movement must be controlled. This ability is one of the features which makes corrugated board a better material for boxes than solid fiber or wood.

7. *Compatibility.* The container and its contents must be compatible with each other. That is, there should be nothing in the container itself which can damage the contents or vice versa. For example, the presence in liner board of free sulphur even in very small quantities can tarnish silverware packed in a box made from this board.

8. *Support.* Package may require additional support to that offered by the container itself. Such additional support must be provided where needed and in the direction needed. Example—not needed in canned goods box but would be needed in box for fragile piece of furniture.

9. *Clearance—Surface Protection.* Finished or fragile surfaces must be protected from contact with inside surface of container. This is to protect against blows that may penetrate outer wall or to prevent abrasion or marring of surface from contact with container. This is generally accomplished by use of spacing blocks and protective wraps such as waxed paper or creped cellulose wadding.

10. *Distribution of Load-Bearing Surfaces.* Bearing blocks and interior fittings should contact largest possible surfaces to avoid excessive pressures developed in small areas.

11. *Position.* Article must be placed in container in most favorable position to withstand impacts and other hazards. An obvious example would be glass bottles which are placed upright, not on their sides.

12. *Suspension.* When we hang an article more or less free in a container by having it bear against solid supports on only one or two faces, we are employing the principle of suspension. This gives complete clearance on other faces and takes care of principle no. 9 by providing excellent surface protection.

13. *Exposure.* Exposing the contents by deliberately cutting holes in the wall of the container. This may be required for ventilation or to allow for inspection. It is also done sometimes with very fragile articles such as x-ray tubes, etc. for psychological reasons. It has been found in many cases that if the freight handlers can see with their own eyes that they are handling a very fragile item, it is more effective than a dozen "Handle with Care" signs.

14. *Closure.* Type of closure, whether glue, stitches, or tape and efficiency with which applied can make a big difference in the performance of a package.

15. *Advertising and Instruction.* It is important to identify the contents, and give proper handling position and any necessary precautions to prevent breakage or injury. Also, it is frequently desirable to exploit the advertising value of corrugated boxes as miniature traveling billboards to advertise the shipper's product.

These are the 15 principles of protection that must be used in more or less degree in all successful packaging. The extent to which each one will be employed, will depend of course upon the nature of the product and the use requirements involved. However, in determining whether or not a proposed container will do a particular job, the packaging engineer will check each of these 15 points to see if it is needed in the design, and if it is, to be sure that it is provided in sufficient degree.

While we have been emphasizing here the importance of providing adequate protection against every reasonable hazard, it is equally important not to go too far and overpackage by protecting against imaginary or unlikely hazards. It is unrealistic and uneconomical to expect every last item to arrive in perfect condition; and if it does, then you can be sure you have a case of gross overpackaging. Of course, the amount of allowable damage will vary with the value of the product and the consequences of damage. The amount of allowable damage in order to reduce container costs would, I should think, be quite different for the shipper of applesauce than it would for the shipper of nylon yarn. For the shipper of dynamite, the tolerance should be zero.

OPTIMUM SHAPES FOR CORRUGATED BOXES

We are all aware how variations in the shape of a box and the relation of its three dimensions can profoundly affect its utility and its cost. There are a few points that should be kept in mind with regard to optimum shapes in corrugated boxes. We know, of course, that in many, perhaps most instances, the shape of the box is fixed, being determined by the shape of the contents. However, there are still plenty of instances where a certain amount of flexibility is allowable in a box shape. This is particularly true of bulk items or contents consisting of a multiplicity of relatively small units.

There are two aspects to optimum shapes of boxes: (1) the optimum shape with relation to handling, and (2) the optimum shape with relation to cost. Unfortunately, both optimums do not coincide so that a certain amount of compromise is necessary. A long skinny box is not desirable because of the heavy impacts generated when it falls end-over-end. On the other hand, a cubical box, although it has a center of gravity well situated in the center of the box and therefore suffers the least in tumbling, has the undesirable characteristic of being unsuitable for palletizing and stacking in bonded block pattern.

It is fairly generally agreed that the best-shaped box for handling and storing is one in which the length is approximately one and a half times the width and the depth is equal to or slightly less than the width. Such a box will stack well and lends itself to palletization very nicely. Also, in this shape, the strength factors are at a good level.

When considering changes in dimensions, it is well to keep in mind possible changes in gross weight which may result. In this connection, it should be noted that the optimum weight for handling is between 40 to 50 lb. Boxes much lighter than this are apt to be thrown or handled more carelessly when unloading a truck or car, and the boxes much over 50 lb. are apt to be so heavy that handlers will let go of them too high off the floor to avoid bending over, thus giving the box a bad drop.

Now, let's look at the effect of various box shapes on cost. The large food companies, who use great quantities of folding boxes, discovered some time ago that the most economical shape from the standpoint of amount of board used to cubic capacity is the half-cube. That is, a box in which the length is twice the width and equal to the depth, or in the proportions $L = 2W = D$.

Since the length and depth are double the width, it is only necessary to find the width in order to get all three dimensions. If we know the volume of a box and want to make the cheapest possible RSC to provide that volume, here is a simple way to find the correct width to use. We know that volume

$= L \times W \times D$. Using the proportions of the cheapest box $L = 2W = D$ and expressing all dimensions in terms of width, we get:

$$\text{Volume} = 2W \times W \times 2W$$
$$V = 4W^3$$
$$W^3 = \frac{V}{4}$$
$$W = \sqrt[3]{\frac{V}{4}}$$

For example, a box 16 by 12 by 8 contains 1536 cu. in. and requires 1120 sq. in. of board (disregarding scoring allowances). The dimensions of the box which will provide the same capacity and require the least amount of board may be determined by use of the above formula as follows:

$$1536 = 4W^3$$
$$W^3 = \frac{1536}{4}$$
$$W = \sqrt[3]{384}$$
$$W = 7\,1/4$$

The cube root of 384 is actually a shade over $7\,1/4$, but we need only go to the nearest sixteenth inch. Having found the width to be $7\,1/4$ in., and since the proportions of the box using the least amount of board are $L = 2W = D$, the dimensions for this box would be $14\,1/2$ by $7\,1/4$ by $14\,1/2$. Such a box requires only 946 sq. in. of board, a saving of almost 16% over the original box.

Many people are under the erroneous impression that for any given volume, the deeper we make the box, the less board we use. That is true only up to a certain point. And that point is the length of the box. As soon as the depth equals the length, we have reached the point of diminishing returns and every inch we add to the depth makes the box less and less economical. It also makes it a more difficult box to handle and store and the great disproportion between width and depth makes it a weaker box. It should be kept in mind that what is being said here applies only to a regular slotted container. For other styles, a different formula is required. The cheapest box in full overlap style, for example, would have the proportion $2L = 4W = D$.

Chesapeake and Allegheny Paper Club

C. E. Libby of North Carolina State University, Raleigh, N. C., and R. G. Macdonald, Secretary of TAPPI, were the speakers at the organization meeting of the Chesapeake and Allegheny Paper Club, held at Richmond, Va., on September 17. Professor Libby spoke of the experience in organizing the Empire State Section of TAPPI, of which he was one of the founders, and emphasized the desirability of building a local club program that would be helpful to its members and their companies in performing their regular work. He also stressed the part that a local club could play in promoting the professional growth of the younger paper technologists in its area.

Mr. Macdonald recounted some of the problems that other newly organized paper clubs had encountered, as well as outlining the historical background of TAPPI, and advised the new club on many matters such as by-laws, dues, meeting places, membership, and programs.

Thirty-two men attended the meeting, at which Robert B. Hobbs, National Bureau of Standards, vice-chairman of the steering committee, presided. The club voted to continue the present steering committee, of which John H. Symes, National Container Corp., is chairman, in office until a permanent organization is effected. The next meeting was set for Friday, November 19, at the Hotel Jefferson, Richmond, Va.

Interested individuals in the Maryland-Virginia-northern North Carolina area who have not already been contacted by the club, are invited to send their names to John J. Priest, membership chairman of the club, Halifax Paper Co., Roanoke Rapids, N. C., to receive notices of future activities.

ROBERT B. HOBBS

Ohio

The Ohio Section held its first meeting of the 1954–55 season at the Manchester Hotel in Middletown, Ohio, on Sept. 16, 1954. Harold Joiner, chairman of the Ohio Section, presided at the meeting.

The Section was indeed fortunate to have for its speaker at the kick-off meeting, W. H. Brecht, Director of the Institute of Paper Manufacturing, Darmstadt, Germany. Mr. Brecht spoke on "Recent Investigations at the Institute of Paper Manufacturing at Darmstadt." Although his paper is not available for publication at the present time, it will be published at a later date. The paper consisted of a discussion of three separate research investigations which are under way at Darmstadt. The first of these was the development of a method for determining the power required for disintegration of various types of pulp. The second was the development of a testing machine to measure the quality of formation in paper. The third was a discussion of the research which has been done in connection with cockle.

W. H. Brecht, Technische Hochschule, Darmstadt, Germany and H. R. Joiner, Champion Paper & Fibre Co.

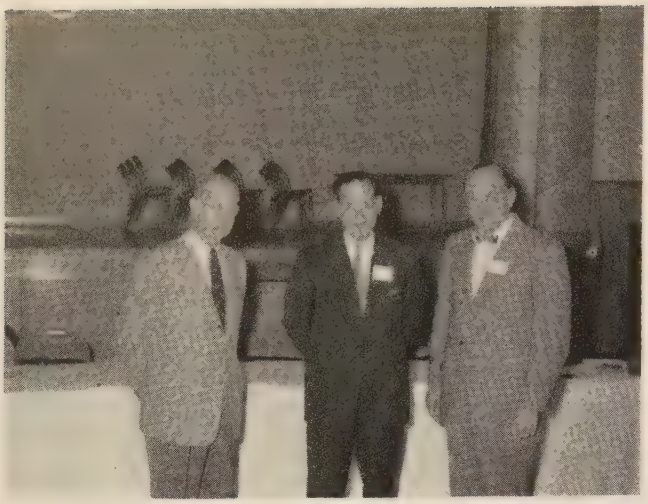
E. W. PETRICH, *Recording Secretary*

Maine-New Hampshire

One hundred and thirty-one delegates attended the Autumn meeting of the Maine-New Hampshire Section of TAPPI, at Edmundston, N. B., September 10–11, 1954. The meeting was under the chairmanship of A. E. Jones, Oxford Paper Co., Rumford, Me., and chairman of the Section.

Roland J. Martin, Frazer Paper Ltd., was elected to serve out the unexpired term of vice-chairman of the Section caused by the resignation of F. N. Sprague, St. Regis Paper Co. Mr. Sprague will continue to serve as a member of the Executive Committee. This action was taken at a meeting of the Executive Committee held Sept. 10, 1954.

Following registration at the Madawaska Inn on Friday morning, September 10, the delegates toured the pulp and paperboard mills of Fraser Cos., Ltd., Edmundston, N. B. There they saw the first half of an international integrated



A. E. Jones, Oxford Paper Co.; A. H. Nissan, The University, Leeds, England; and R. J. Martin, Fraser Paper, Ltd.

pulp and paper operation. The pulp made and prepared in Edmundston is pumped through a mile-long pipe which passes over the international boundary, the Saint John River, into the fine paper mills of Fraser Paper, Ltd. in Madawaska, Me.

In the afternoon, Alfred H. Nissan, research professor of Wool Textile Engineering, Dept. of Textile Industries, the University of Leeds, England, presented a paper entitled, "An Analytical Approach to the Problem of Drying of Thin Fibrous Sheets on Multi-Cylinder Machines." Mr. Nissan, who was formerly with Bowaters Research and Development Ltd., was in this country to attend the international symposium on the fundamentals of the paper machine which was held at The Institute of Paper Chemistry, Appleton, Wis., by the Fundamental Research Committees of TAPPI and the Technical Section, Canadian Pulp and Paper Association.

Following Mr. Nissan's paper, the delegates crossed over the international boundary to visit the paper mills of Fraser Paper, Ltd. at Madawaska, Me. There they saw the pulp from the Edmundston mill turned into bond and business papers in the bond mill and groundwood specialty papers in the catalog mill.

In the evening a banquet was held in Edmundston. Aubrey Crabtree, president, Fraser Cos., Ltd., welcomed the members in their visit to the company's mills and forest operations. Following the dinner, there was a dance at the Edmundston Golf Club for the delegates and their wives.

On Saturday morning awards were presented for the Section's Worthen E. Brawn competition. Sponsored by the Section, this competition is designed to encourage technical research and investigation by young men. Papers submitted by entrants are judged by the Section's judging committee. The best paper in the committee's opinion receives an award of $100 and the second, $50. Cash awards are also made to other entrants. A maximum of $250 is provided by the Section each year for this competition in memory of its founder, the late Worthen E. Brawn, who established the Section in 1940 and was president of National TAPPI when he died in 1947.

This year's first award winner was W. H. Hoge, group leader of fundamental research, Oxford Paper Co., Rumford, Me. Mr. Hoge read his prize-winning paper entitled, "The Detection of Lignin." Occasionally, he said, a test is required to determine whether a sample of pulp contains lignin. In the study of certain process residues, it can sometimes be very helpful to know if the lignin is hardwood or softwood in origin. Color reactions often are unsuitable and in most instances they do not give specific distances for lignin. He described a qualitative procedure for the detection of lignin. The lignin is oxidized with Fehling's solution and the vanillin and syringaldehyde are identified on a paper chromatogram. The presence of syringaldehyde indicates hardwood lignin. The method requires no specialized equipment, said Mr. Hoge, and the results can be obtained in about 4 hr. The procedure, he said, has been successfully applied to sulphite liquors, kraft liquors, and uncooked wood chips.

Mr. Hoge of Dayton, Ohio, obtained his Bachelor of Chemical Engineering degree at the Ohio State University in 1949. In 1951 he received his master's degree at The Institute of Paper Chemistry and his doctor's degree from the Institute this year.

Winner of the second Worthen E. Brawn award was Albert J. Marchand, chemist, Fraser Paper, Ltd., Madawaska, Me. Mr. Marchand read his prize-winning paper on "Latex Retention." Adding resin to beaten fibers is not a new subject, he said. Many mills are producing resin containing sheets on a full-scale basis using the beater addition technique. He described his investigation of the effect of final beater pH and white water recirculation on the retention of plasticized polyvinyl chloride using 20% latex with unbleached kraft stock. The resin retention was determined, by the difference in weight between the resin-treated sheets and the untreated "no resin" sheets. Resin and alum were added to the beaten kraft pulp in that order. Only alum was used to coagulate the resin and regulate the pH. White water recirculation on the Noble & Wood handsheet machine increased the resin retention. His investigation showed, said Mr. Marchand, that a low pH in the vicinity of 3.5 gave the best resin retention. It appears that retentions of 90% are not impossible using this method.

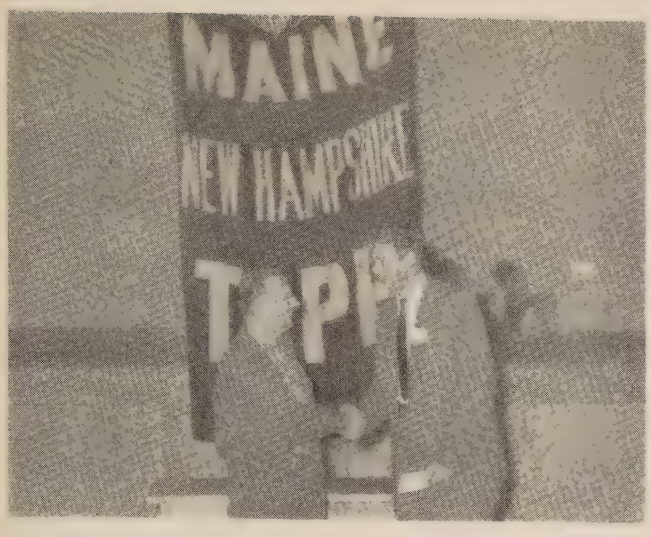
Mr. Marchand, who is 21 years of age, holds the degree of Bachelor of Science in Paper Engineering from the Lowell Technological Institute. He received his degree upon graduation last June and since that time has been employed at Fraser Paper, Ltd.

After the presentation of the awards and the reading of the papers, the delegates motored to the nearby Basley Lake camp headquarters of the Murchie Seigniory, forest management property owned by Fraser Co., Ltd. There they saw demonstrations of pulpwood cutting by power saws and fire fighting methods, following which they enjoyed a lumberjack lunch at the woods camp.

In the afternoon there was to have been a golf tournament and fishing derby. These were canceled because of the heavy rains and high winds caused by Hurricane Edna.

Wives of several of the delegates attended the meeting and a special program was conducted for them. This included a

J. J. Thomas, S. D. Warren Co. and W. H. Hoge, Oxford Paper Co.



J. J. Thomas, S. D. Warren Co. and A. J. Marchand, Fraser, Paper, Ltd.

trip to St. Leonards, N. B., where they saw the operations of a famous handweaving establishment.

The committees in charge of the meeting were:

Local Arrangements: J. F. Wright, National Aniline Div., Boston, Mass.; H. E. Pratt, Pejepscot Paper Div., Brunswick, Me.; R. J. Martin, Fraser Paper, Ltd., Madawaska, Me.; and E. R. Hunting, Fraser Paper, Ltd., Madawaska, Me.

Golf: J. S. Overbagh, Fraser Co., Ltd., Edmundston, N. B., and W. E. Wentworth, Clinton Foods, Inc., Somerville, Mass.

Public Relations: W. L. Hinds, Keyes Fibre Co., Waterville, Me. and E. N. Poor, Hudson Pulp & Paper Corp., Augusta, Me.

Ladies Entertainment Committee: Mrs. R. J. Martin, Madawaska, Me., and Mrs. A. E. Jones, Rumford, Me.

Fishing: W. C. Novack, Fraser Paper, Ltd., Edmundston, N. B.; R. O. Lindsey, American Cyanamid Co., Boston, Mass.; and F. A. Strovink, American Cyanamid Co., Boston, Mass.

Technical Program: F. N. Sprague, St. Regis Paper Co., Bucksport, Me., and H. S. Hooper, Penobscot Chemical Fibre Co., Great Works, Me.

Woods Trip: D. W. Hudson and E. L. Howie, Fraser Co.,

W. L. Hinds, *Chairman*
Public Relations Committee

Pacific

The first meeting of this fiscal year was held at the Multnomah Hotel in Portland, Ore., on Sept. 29, 1954.

The technical meeting was called at 2:00 p.m. and was headed up by Leland F. Mayback, Crown Zellerbach Corp., Camas, Wash. The following four papers were presented at this meeting:

"Kamyr Continuous Cooking," by Lennart Lundberg, project engineer, A. H. Lundberg, Inc.

"Recent Improvements in the West Linn Sulphite Mill," by R. Plankinton, technical assistant to sulphite mill superintendent, West Linn Div., Crown Zellerbach Corp.

"Welding of Stationary Kraft Digesters," by George Conner, welding engineer, Willamette Iron & Steel Co.

"Industrial Engineering in a Crown Zellerbach Mill," by T. W. Leedham, division industrial engineer, Camas Div., Crown Zellerbach Corp.

The technical meeting was followed by a social hour at 5:30 p.m. and dinner at 6:30 p.m. The after-dinner speaker was Herbert F. Rance, The Wiggins Teape Group Research Organization, Woodburn Green, Bucks, England. Mr. Rance was visiting the Pacific Northwest at this time primarily to present the 8th annual seminar on the structure of paper.

The next Pacific Section meeting will be held in Bellingham, Wash., on Nov. 9, 1954.

Kamyr Continuous Cooking

Lennart A. Lundberg

My year in Sweden gave me the opportunity to study closely the Kamyr continuous digester, and I would like to pass along to you—in capsule form, of course—some of the details of this new process.

It is the first continuous process which retains the characteristics of the conventional batch system, and while our present knowledge is based on operations of only 30 to 60 tons per day, three 100-ton plus per day units have been built. The first of these is scheduled to start up the first of October at Wifstavarf, Sweden—it is a 100% scale up and will be an excellent test of the equipment. One fact which has not been investigated is the minimum cooking time required under the uniform operating conditions existing in the digesters. As most of the mills in Europe operate with a rather limited wood supply, we shall probably have to wait until a unit is installed in the United States. A 60-ton unit in Japan has been averaging 85 tons the last few months with a peak output of 92 tons. If these results have been obtained without sacrificing necessary pulp characteristics, then the unit purchased today will take care of tomorrow's expansion.

FLOW OF MATERIALS

The chips are brought in, either continuously, or a sufficiently large overhead storage bin can be installed. The production is set by a variable speed chip meter which can be adjusted to regulate the volumetric flow of chips to the unit. They next pass through the low pressure feeder, which is a simple star-type valve designed to operate against a 50-lb. steam pressure, then through the steaming vessel where they are heated by means of the flash blow steam to about 212°F, and drop into the chip chute to the high pressure feeder. This feeder is really the heart of the whole system.

The chips are pumped into the pocket of the feeder, and as it rotates 90°, the chips are pumped to the top of the digester. In the larger units, four pockets are provided, each at 45°, so that, in practice, a continuous flow of chips is attained. As you can see, this feeder is perfectly balanced, and should experience very little wear. Current practice on existing units is to regrind the rotor about once a year. The rotating element

Lennart A. Lundberg, Project Engineer, A. H. Lundberg, Inc., Portland Ore.

H. F. Rance, The Wiggins Teape Group Research Organization and Mrs. Rance

L. F. Mayback and J. H. Hull of the Crown Zellerbach Corp.

is conical so that considerable wear can be compensated for before a new sleeve is required.

As the chips are pumped into the top of the digester, the liquor returns through a strainer to pick up the next batch while the chips are guided downward into the digester by means of a screw mounted inside the strainer. This screw also serves to keep the strainer clean.

The cooking liquor is added to the level tank, which also receives the liquor displaced by the chips, and is pumped by means of a high pressure pump into the digester. A pressure control system on the discharge of this pump maintains the pressure of about 140 lb. in the digester, or 20 to 30 lb. over the equivalent steam pressure at the bottom of the digester. This serves to prevent boiling and holds the temperature down in the cooking zone of the digester.

If the top temperature of the digester exceeds 220°F, as it does during start-ups, considerable flashing will take place in the feeder. For this reason, an auxiliary cooling unit is provided to cool the top circulation liquor during start-up.

An interesting side light on the effect of this overpressure is the absence of flashing across the circulation strainers, and, as a consequence, there has been no scaling in the strainer, and practically none in the heater.

As the chips move downward through the digester, they pass successively through two heating zones. These can be located, at the option of the operator, to provide whatever cooking curve is desired.

At the bottom of the digester, the cooked pulp is diluted to about 8% consistency and is delivered through a short blow line to a strainer arrangement where the pulp is thickened to about 15% consistency before the blow valve. A scraper arrangement aids in the uniform removal of the pulp. The blow valve consists of two plungers in series, one of which is always closed.

The stock then discharges to the blow tank where the flash steam is returned to the steaming vessel for preheating the chips, and in the bottom portion is diluted for transporting to the brown stock washing system.

CORROSION PROTECTION

All pumps: stainless steel throughout
Low pressure feeder: Housing—stainless steel
Rotor—cast iron with monel sleeve
Steaming vessel: screw—stainless steel
Chip chute: stainless steel
High pressure feeder: Housing—cast steel with monel sleeve
Rotor—stainless steel
Top circulation lines—stainless steel
Top separator unit—stainless steel
Strainers and central pipe—stainless steel
Bottom scraper—stainless steel
Blow line and blow valve—stainless steel

POWER CONSUMPTION

Due to the low net liquor to wood ratio passing through the digester and the direct use of the blow steam for preheating the chips, the steam consumption is quite low, varying between 2000 and 2400 lb. per ton. For economical heater design, steam pressure of about 190 to 200 p.s.i. is required.

Due to its batch operation, the digester department in a conventional mill probably requires the largest amount of reserve power capacity. With continuous cooking, this peaking is virtually eliminated and the reserve power can be utilized elsewhere.

EQUIPMENT ARRANGEMENT

This equipment is preferably arranged compactly and lends itself admirably to integration with other pulp mill operations such as washing and screening, all of which may be located on the same operating floor. Since these other operations are all continuous and normally required a minimum of attention the same crew could, conceivably, run this entire portion of the plant with the elimination of one, two, or three men.

In conclusion, I must say that I am completely enthusiastic about the possibility of this new method of doing an old job better. I expect the continuous cooking system to replace most of the batch cooking equipment in this country before too many years have passed, and while it may be overly optimistic to think Kamyr equipment will be preferred, at the present time nothing else is available for producers of full cooked kraft.

Recent Improvements to the West Linn Sulphite Mill

R. Plankinton

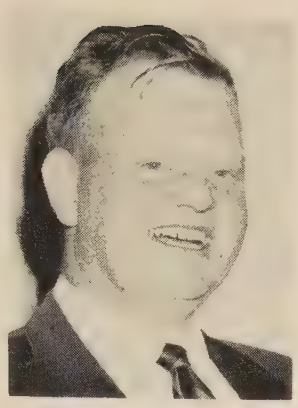
Two years ago sulphite pulp usage at the West Linn mill of Crown Zellerbach Corp. had risen to a level well in excess of the capacity of the five-digester sulphite mill even though cooking time had been cut to under 8 hr. cover to cover. At that time a hot acid relief recovery system was in use. Low pressure digester relief and accumulator overgas went to distribution pipes in the bottom of the reclaiming tanks which were in turn vented to the strong Jenssen tower.

Digester forced circulating and indirect heating systems, which were installed in 1950, gave considerable operating difficulty because of scaling and corrosion. For this reason its use was discontinued pending the installation of new equipment to be discussed later.

R. Plankinton, Technical Assistant to the Sulphite Superintendent, West Linn Div., Crown Zellerbach, Corp., West Linn, Ore.

T. W. Leedham, Crown Zellerbach Corp., and L. A. Lundberg, A. H. Lundberg, Inc.

K. G. Booth, Crown Zellerbach Corp.



R. Plankinton, Crown Zellerbach Corp.

Cooking acid obtainable at that time was not strong enough to permit further increases in digester production by chip packing.

Digester temperatures higher than optimum for the best quality had to be employed to produce pulp of the softness required by the paper mill.

In order to improve the quality of sulphite pulp at West Linn, two conditions had to be met: (1) digester temperatures not to exceed 285°F., and (2) good liquor circulation throughout the digester charge.

Maximum cooking temperatures could not be reduced until sufficient sulphur dioxide was made available in the digester to take the place of heat. In the final analysis, the only practical way this could be done was by making possible the burning of more sulphur in the acid plant. The obvious method of increasing the sulphur-burning capacity of the acid plant was to eliminate the return of strong digester relief gases to the Jenssen towers. To this end a three-tower relief recovery system was installed.

Three factors adversely affected trouble-free operation of the digester circulating systems: (1) sulphur combustion control was inadequate favoring formation of sulphur trioxide which contributed to scaling, (2) during the Summer months the temperature of the river water which is used in acid making rises to 74 to 78°F., too high to absorb sufficient free SO_2 in passage through the Jenssen towers, and (3) cooking acid was too low in free SO_2 to prevent scale precipitation.

The relief recovery system could be counted on to provide sufficiently strong acid to insure against liming 8 months of the year. Also, by eliminating the intermittent return of digester relief, the recovery system allows for constant back pressure on the sulphur burner. To obtain further improvement in combustion control the three small burners and combustion chambers were replaced with large single units. In order to hold raw acid strength up during periods of critical water temperature, a raw acid booster tower and gas compressor to supply it were installed.

Each of the above improvements will be covered in more detail in the following discussion. The various data to be presented are typical of recent Summer-time operation. Acid strengths do, of course, vary with water temperature and with moisture content of the wood being cooked. All acid tests were run with standard iodate and caustic soda. All gas tests were run with a standard Orsat apparatus using iodine for sulphur dioxide and caustic for carbon dioxide. Water in relief gases was determined using weighed calcium chloride drying tubes. Nitrogen which includes small amounts of other inerts was found by difference. Tail gas tower exhaust differed from the above pattern in that sulphur dioxide was determined by the method of Reich. All gas tests were corrected to standard conditions. For convenience these data are collected in Tables I and II.

RELIEF RECOVERY SYSTEM

The relief recovery system consists of four units, the hot acid accumulator and the three new units: the pressure tower, atmospheric tower, and tail gas tower along with necessary piping, pumps, and valves.

Accumulator

The 82,000-gal. accumulator is a brick-lined and lagged steel shell built for 150 p.s.i.g. working pressure. It receives side relief and high pressure relief from the digesters via the eductor and is instrument controlled to 40 p.s.i.g. Acid temperature in the accumulator currently averages 160°F. Some control over temperature is provided by the relief coolers. The cooking acid pumped to the digesters averages about 7.3% total and 1.22% combined SO_2.

Pressure Tower

The pressure tower which receives both low pressure digester relief and overgas from the accumulator is a 6-ft. 4-in. by 40-ft. steel tile-lined tank built to withstand digester pressure. It is packed with 25 ft. of 3 by 3-in. cross-partition tile stacked in staggered layers. Instrumentation includes: (1) a liquid level recorder controller which holds a liquid seal in the bottom of the tower by throttling the pump pumping acid to the accumulator by way of the eductor, (2) an acid temperature recorder, and (3) a pressure recorder controller which operates a valve in the overgas line.

In addition, working off the pressure instrument is a vacuum breaker which automatically opens the accumulator pressure control valve whenever the pressure in the tower falls to 1 p.s.i.g. and closes it again at 2 p.s.i.g. This is a precaution against damage to the tower lining caused by a reduced pressure in the tower. Soon to be added is an integrating acid flow recorder in the line carrying tank acid to the pressure tower.

The pressure controller is set for 18 p.s.i.g. but actually the pressure is below this value about half the time because of variation in the flow of relief from the digesters.

Tank acid enters the top of the tower at about 4.90% total and 1.81% combined SO_2 and leaves at an average test of 6.80% total and 1.77 combined. Tests as high as 8.30% and as low as 5.30% total are regularly observable. This variation, of course, coincides with varying digester relief.

Atmospheric Tower

The atmospheric tower which receives the overgas from the pressure tower is of wood stave construction 3 ft 2 in. by 40 ft. and packed with 24 ft. of 3 by 3-in. cross-partition tile with 1 ft. of $1^1/_2$ by $1^1/_2$-in. Raschig rings dumped on top. Raw acid from the booster tower is pumped over the packing. A liquid level recorder controller holds a seal in the bottom of the tower by throttling a gravity flow to the acid tanks. The increase in acid strength through this tower is small

Table I. Typical Gas Tests

	Temperature, °F.	*SO_2, %*	*H_2O, %*	*CO_2, %*	*N_2, etc., %*
No. 1 digester blow back	260	87.9	7.1	4.0	1.0
Accumulator overgas	160	91.0	5.7	2.3	1.0
Pressure tower overgas	86	49.3	1.7	39.2	9.8
Atmospheric tower overgas	84	24.0	1.6	59.5	14.9
Tank vent gas	84	54.0	4.3	33.8	7.9
Tail gas tower exhaust	67	0.3	1.7	79.2	19.8
Burner gas	1900	17.5	1.6	0.4	80.5
Booster tower overgas (operating pressure 8 p.s.i.g.)	83	11.7	1.9	1.1	85.3

primarily because of very efficient operation of the pressure tower. Acid enters the tower at about 4.88% total and 1.82% combined SO_2. Tank acid averages 4.90% total and 1.81% combined. Soon to be added is provision for pumping tank acid over this tower to permit operation of the sulphite mill during short acid plant shutdowns.

Table II. Typical Acid Tests

	Temperature, °F.	*Total SO_2, %*	*Free SO_2, %*	*Combined SO_2, %*
Strong Jenssen tower	82	4.40	2.46	1.94
Booster tower (operating pressure 8 p.s.i.g.)	86	4.88	3.06	1.82
Tanks	84	4.90	3.09	1.81
Pressure recovery tower				
Maximum relief flow	88	8.00	6.50	1.74
Minimum relief flow	85	5.30	3.50	1.80
Average relief flow	86	6.80	5.03	1.77
Accumulator	160	7.00	5.78	1.22
Tail gas tower effluent	66	0.23	0.23	0

It should be pointed out that this recovery system was designed to accommodate one additional 18-ton digester. With six digesters on the line gas flow to the recovery system would be more uniform. As a result, the pressure tower would be up to pressure more of the time and, therefore, the flow to the atmospheric tower would be increased.

The acid storage tanks are vented to the tail gas tower instead of the more common arrangement of venting to the atmospheric tower. This change from the original plan was made necessary because of the design of the atmospheric tower packing support. This is built of 2-in. boards set on edge 2 in. apart, which arrangement cuts down on the 42% open area of the 3-in. tile to 21% at the point of junction between packing and packing support. This restriction causes flooding of the packing at this point. The column of acid held back in the tower by the flooded point exerts a pressure of about $1^1/_2$ p.s.i.g. on the tower cistern. This pressure is too great to permit venting the tanks, which are equipped with 14-in. water seals, to the atmospheric tower.

Plans are now ready for adding a stainless steel grid on top of the present support to eliminate the restriction. This change becomes especially desirable when considered in light of the fact that the accumulator must be emptied periodically for inspection and lining repair. At such times all of the digester relief will have to be led directly to the reclaiming tanks which in turn will have to be vented to the atmospheric tower to prevent return of relief to the acid plant.

Tail Gas Tower

The tail gas tower is a 2-ft. 6-in. by 35-ft. wooden stave unit packed with 2-ft. of 3 by 3-in. cross-partition tile placed in staggered layers with 28 ft. of $1^1/_2$ by $1^1/_2$-in. Raschig rings dumped on top. A 10 g.p.m. flow of water is metered to a distribution plate at the top and flows freely from the bottom through a 3 ft. trap to the cistern of the weak Jenssen tower. This effluent averages less than 0.25% SO_2 which amounts to less than 0.3% of the total sulphur burned. It is the only portion of the digester relief which finds its way back to the acid plant.

General

Maximum gas tests during blow back on no. 1 digester are shown for various points through the system in Table I. It should be pointed out that the very small percentage of inerts contained in digester relief make up almost all of the gas exhausted from the tail gas tower. On this basis the recovery system is well over 99.5% efficient in absorbing sulphur dioxide from digester relief.

It is interesting to note that a two-digester mill would require almost the same recovery system as one having up to six digesters of similar size. This is true because the system must be sized for maximum gas flow, i.e., blow back on the largest digester in the mill.

ACID PLANT

Sulphur Burning

The new 5 by 16-ft. brick-lined sulphur burner and 10 by 14-ft. brick-lined combustion chamber which have replaced the old three burner setup produce a uniform flow of 17.5% gas which leaves the combustion chamber at nearly 1900°F. An important contributor to burner gas uniformity is the elimination of digester relief flow to the Jenssen towers and the concomitant elimination of varying back pressure on the burner. Secondary air which is manually controlled is preheated by being drawn past the combustion chamber and burner inside of a partial housing around these two units. The flow of molten sulphur to the burner is controlled by a liquid level recorder controller which throttles a pump pumping from one of two new sulphur melting tanks. Each of these tanks which are rectangular reinforced concrete sumps set in the floor of the acid plant has a capacity of 30 tons of molten sulphur.

The increase in burner gas concentration from 14 to 17.5% has brought about an 0.2% increase in free sulphur dioxide content of the strong Jenssen tower acid.

Booster Tower

The raw acid booster tower is a steel tile lined tank 5 ft. 6 in. by 35 ft. built for 50 p.s.i.g. working pressure. It is packed with 21 ft. of 6 by 6-in. spiral tile and 9 in. by 3 by 3-in., cross partition tile both stacked in staggered layers, and 3 in. of Berl saddles dumped on top.

Instrumentation consists of a pressure recorder controller which operates a valve in the overgas line and a liquid level recorder controller which holds a gas seal in the cistern of the tower by throttling the pump which pumps from the booster tower to the atmospheric tower in the recovery system. Cooled burner gas is pumped from the suction side of the gas fan by an 8 by 8-in. Bingham compressor made of type 316 stainless steel. The overgas is returned to the system on the pressure side of the gas fan. The gas enters the tower at 17.5% and leaves at 9 to 13% depending upon tower pressure and acid temperature. During recent operation with the acid leaving the Jenssen towers at 82°F. and the booster tower operating at 8 p.s.i.g. the overgas concentration has been 11.7% SO_2. Under these same conditions the acid enters at 4.40% total and 1.94% combined SO_2 and leaves at 4.84% total and 1.82% combined. The drop in combined sulphur dioxide is explained by the seal water used in the compressor and then mixed with the acid in the cistern of the tower. The increase in total sulphur dioxide of 0.44% based on the raw acid plus sealing water is very close to the designed pick-up in the tower packing which leads us to believe that the sealing water is absorbing its share of sulphur dioxide in the compressor. Very satisfactory control over cooking acid strength is achieved by varying booster tower pressure to meet changing conditions.

CONCLUSION

Now that the new equipment has been in service for some months the following conclusions can be drawn concerning its worth:

1. The digester circulating systems have given no real operating trouble. Frequent inspections of circulation piping have so far revealed no serious corrosion or scaling.

2. Maximum digester temperatures of not over 285°F. have been realized and pulp strength has been improved.

3. Chip packing using steam is being successfully carried out to the extent that digester production has been increased 7 to 8% with only occasional dirty blows.

Industrial Engineering in a Crown Zellerbach Corp. Mill

T. W. Leedham

WHY have engineers in a paper mill? Don't look too startled at a question of this kind, because I am sure such a thought has crossed many a manager's mind. Paper mills spend considerable money each year for engineering. Perhaps it would be well just to save that money by eliminating the use of engineers. I don't think we need to worry much, however, because engineering services are recognized as a necessary part of any industrial organization. Engineering services have become necessary as business has grown more complex. Further, this very complexity has changed the character of engineering.

I suspect that when the first plant manager decided to assign work along a mechanical, electrical, and structural line, he considered that an engineer could handle all of these. Time has proved, however, that we have many fields of engineering, and even today we have subdivisions of these fields with specialists for each.

The electrical engineer is a rare one who admits publicly that he knows everything there is to know about the electrical engineering field. We have electronic specialists and power specialists, to name only a couple.

In the mechanical engineering line a man would be foolhardy to say that he knows everything there is to know about machine design, servomechanism, and mechanical devices.

In civil engineering the field has become broken down into structural men, surveyors, and hydraulic experts.

As an industrial organization has become more complex, managers have felt the need for specialists in all lines to provide the service necessary for line operation. In addition to servicing the equipment, the structure, and the power plant, management has found it desirable to use engineers in another specialized field—this is the field of inter-relationship between men, machines, and economics; and concerns itself with productivity and cost reduction. The engineers handling this type of service in Crown Zellerbach have been designated as industrial engineers.

The work covered by our industrial engineers is done in every industrial organization by someone. They may not necessarily be called industrial engineers; nor is the work necessarily assigned to one individual or to one group; but this work is necessary if an industrial enterprise intends to stay healthy. The projects handled by industrial engineers in Crown Zellerbach Corp. are mainly methods improvement and cost reduction items.

Specifically, almost any change is a methods improvement, and if the business is to continue to prosper, almost every change should effect a reduction in cost. Generally speaking, our work falls into a number of different categories; plant layout, economic studies, materials handling, warehousing, method studies, packaging studies, standards, and production control procedures.

Plant layout can involve the addition of new equipment into an existing production line. We have examples of this problem almost continuously, and I suspect that each of you in your own plants are faced with similar problems.

The plant layout using new equipment in an existing situation is one of compromises; and the compromise is very often unsatisfactory in one or more respects, no matter how carefully the problem has been worked out. The layout very often represents the proposal having the fewest number of disadvantages.

Such a problem was faced in our own converting plant at Camas when it was decided to produce a new folded towel. This was the first such machine to be installed in Camas. When the layout was made there was no available space to move the machine. It was necessary to relocate one machine and to rearrange the layout for material feeding another machine. The new machine could then be installed; and the work place that was provided offered a convenient setup for the girls who had to attend the machine.

Very often in plant layout one has to outguess, if possible, what the future moves may be in relation to a projected change. In the case of the example this has been considered, and based on the addition of certain faster operating equipment, we expect we could add more machines adjacent to the one that was installed to increase our output.

On occasion an industrial engineering department may be called upon to assist in laying out an entire new plant. This was the case in the Crown Zellerbach converting plants in San Leandro and in Los Angeles.

The problems of laying out a new facility such as these included many different variables such as: storage space for parent stock that would be secured from other Crown mills, flow of materials through the converting operations, new equipment that would be installed which operated in somewhat different manner than that in existing mills, disposition of finished production, disposition of waste materials, storage of finished products, and the handling of materials into the various means of transportation to the customer.

In this over-all problem avoiding unnecessary handling was a primary consideration. The assignment called for developing a layout in which the flow of materials would require a minimum of handling, without congestion at any point, which would allow for future expansion without extensive relay out of existing areas.

Economic studies sometimes concern themselves with various alternates to determine which is the most advantageous. In this developing of alternate plans rough estimates are prepared relating to cost of equipment, cost of installation, and cost of operating. They serve to determine which alternate is the most attractive. In this way, other engineers such as mechanical, civil, and electrical can be spared the tedious detailing and calculating of alternate proposals of which only one will be used.

Economic studies that take a sudden twist once in a while show unexpected savings. As an example, for some time our converting plant in Camas has been interested in using a mechanical baler for baling up the waste paper before returning it to the beaters. The present practice is to hand bale the waste in loose, paper wrapped bales. For quite some time this mechanical baler proposal was found to be economically unsound because there was no labor saving to be realized from the addition of the baling machine. However, a little more detailed study showed a loss in waste paper value that had not been considered.

The Camas converting plant makes several different colors of toilet tissue. The paper machines' colors often do not coincide with the colors in the converting plant. The waste produced in the converting plant when a color is not being run on the paper machines was being lapped out as millwrap broke, used in a lower grade, or on occasion sent to the fire pit for burning. By checking the volume of waste involved, and showing that each of these colors could be stored in compact bales until a run of the color was made on the machine, the value of the waste was found considerably greater. The baling machine has recently been installed and is expected to save a substantial amount of pulp that was formerly being inefficiently re-used.

We have discussed materials handling as it related to the layout of San Leandro and Los Angeles. Materials handling is a phase of industrial operation which offers the greatest single possibility for cost reduction. Some industrialists estimate that materials handling represents as much as 35% of the cost of manufacture.

In the paper industry considerable change has been made in recent years. At Camas the industrial engineering de-

T. W. LEEDHAM, Division Industrial Engineer, Crown Zellerbach Corp., Camas, Wash.

partment has been called upon to check various handling problems. A number of them have been solved through the use of roll grabs. I suspect that almost every paper mill in the West Coast is now using a roll grab of some sort.

At Camas recently another materials handling problem presented itself. Sulphur in fair quantities is being received by rail from Wyoming. A unit crane removes the sulphur from the rail car and dumps it into a truck which in turn transports the sulphur to the storage pile. An alternate is being considered which will involve the use of hopper bottom cars. The sulphur will be loaded from the cars into the truck by means of a portable cross conveyor. This should offer savings over the present method by speeding up the round trip travel of the truck. We are currently working on this project.

The handling of incoming material presents a problem in every plant. In the Camas mill pallet loading patterns have been developed for each raw material. The pallet loading crew uses these patterns when unloading cars of materials. The sacks are stuck together on the pallet with a couple of dabs of glue. The resultant unit is stable so that all products can be transported with a minimum of spillage and loss.

Almost everyone is interested in cost reduction, and suggestions for cost reduction originate from a variety of sources. One of the current sources of cost reduction is the compacting of wood chips for transporting. The wood chips destined for the Camas mill are loaded in rail cars from a number of different saw mills. Compacting was a timber department recommendation and carried with it certain problems of unloading at the mill. The industrial engineering department at Camas has cooperated in determining the best way for sampling and weighing these wood chips when they arrive at the mill. We believe the installation which has recently been completed to be an economical solution to the problem.

Warehousing of finished products can be a headache in any expanding mill. The Crown mills around the Portland area are no exception. As a result of an assignment a year ago, industrial engineering has helped develop a plan for storing finished products in a Portland warehouse from which customer orders would be made up. This was rather an ambitious undertaking. It involved problems of transportation, problems of handling, storing regular inventory control, and order filling.

As a problem, this assignment did not fall into any of the other engineering categories such as civil, mechanical, or electrical, and actually was one of the type best suited to the industrial engineering group. It required coordination with many other staff groups in the organization before the final plan was evolved.

Someone has once said if you have been doing a job a certain way for over 5 years it is time to check to see if there is some better way of doing it. Such a look-see can prove very profitable.

At the Camas mill one such method study involved rewinding of household waxed lunch rolls. Shortly after the war four new rewinders were purchased for this production. These rewinders at that time were considered the most modern and efficient that could be purchased. They used a parent roll 12 in. wide and about 25 in. in diameter. Each machine automatically measured out 125 ft. of waxed paper on a $1^1/_2$-in. core, cut if off, and started the sheet on the next core.

Review of this operation about 3 years ago pointed out the high waste that was being experienced both on the rewinders and at the waxer. This was due in part to narrow rolls and in part to mechanical complexities in the rewinders. A continuous rewinder using a 60-in. web was found to offer new production advantages over the single width machines. After the economics were calculated a floor layout had to be developed to tie the 60-in. machine in with the carton folder and the case sealer. As a result of this study, four machines were replaced with a single machine, even though the four machines were almost new.

Packaging is an important part of a manufacturing operation. It helps sell the product, especially since impulse buying under self service has become an important factor.

If all customer merchandise were hand packaged the chances are there would be no problem with the appearance of the finished product, because the person doing the wrapping or boxing could adjust for any minor difference either in the the outside package or the product inside the package. However, when modern machinery is used, certain tolerances are necessary both in the label and in the wrapping operation.

This problem has been one which is assigned to the industrial engineering department. We have determined from the operating departments the mechanical limitations of the various wrapping machines. Using these limitations it is possible to develop block layouts for an wrapper design so that the art department can develop designs which will appear neatly even though the package is not exactly wrapped perfectly each time. This is a matter of economics, packages that appear poorly wrapped must be rewrapped at additional cost in wrapping labor as well as additional cost in wrapping materials.

Drawings are maintained of all wrapping designs and any time a change is requested it is checked with these drawings to determine if the change will cause any problem in actual production.

You will note in these examples that similar assignments are being done by people in your mill, not necessarily called industrial engineers. Perhaps you are doing some of them yourself. Also, you occasionally do other work not exactly fitting into your particular branch of engineering. With all branches of engineering there is a certain amount of overlapping. Actually, all service functions overlap to a certain extent.

The ideal situation in a manufacturing department is for the supervisor to handle his own mechanical engineering, civil engineering, industrial relations, technical control, and industrial engineering. He is best qualified to know his own problems and to develop the answers if he has the time. However, such a man exists only as "Superman."

For this reason management has assigned various service functions to others. Crown Zellerbach has included industrial engineering in this group because it is recognized as a separate and necessary part of good management.

Only for as long as line management stays progressive and aggressive will an enterprise prosper. Each service department can justify its place on the management team only through handling effective service to the line. We, as industrial engineers at Crown Zellerbach recognize this challenge.

Southeastern

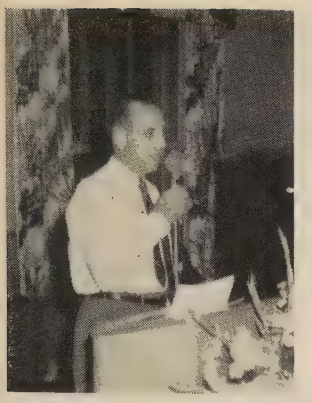
The first meeting of the Southeastern Section of TAPPI was held at the Valdosta Country Club, Valdosta, Ga., on Oct. 1, 1954.

National Container Corp.'s new plant near Valdosta, Ga., was host mill for the meeting. The mill was open for tours Saturday morning.

Registration of nearly 200 members and guests preceded the social hour. Dinner, smorgasbord style, was served at 7 p.m.

Mr. Pineo, section chairman, introduced K. M. Guest, plant manager of the Valdosta mill. Mr. Guest welcomed the group on behalf of National Container. Later in the program, Mr. Guest described briefly the Valdosta mill and their plan for the mill tour on Saturday. Data on various mill equipment were printed on placards at appropriate locations. These, together with arrows for directions, enabled the visitors to proceed through the mill, spending time at places of greatest interest to them.

The technical program was in charge of W. C. Chapman of Union Bag & Paper Corp.



M. B. Pineo, Chairman, Southeastern Section

W. T. Webster, National Container Corp.

Mr. Webster, vice-president and general manager, National Container Corp., discussed the "Selection of Valdosta as a Mill Site." He presented a very interesting review of the preliminary investigations and problems which had to be overcome in locating a mill at Valdosta. One of the prime considerations was the stabilization of the pulp and paper mill wastes so that no deleterious effect would be caused in the receiving stream. Initial surveys were by means of aerial and highway maps. The present site of the mill was picked because of the natural surface formations. This permitted the development of large ponding areas throughout the run of a small creek to a nearby river.

Preliminary operating results of this system were discussed by Mr. Webster. He stated that better than 95% of the B.O.D. of the waste liquor is removed before it is released into the Withlacoochee River.

An adequate sampling and testing program assists in the proper control of the system.

W. M. Blume of West Virginia Pulp & Paper Co., Charleston, S. C., described their method of "Basket Cooking in Mill Digesters."

He pointed out that they have used this method since 1950 for determination of (1) comparison study of pulping properties of differently prepared pine chips, (2) digester yield, (3) uniformity of cooking within a digester, and (4) pulping studies of different types of wood.

The procedure as described is relatively simple. Some disadvantages were described, such as the danger of losing a basket and plugging a blow line. With properly designed baskets and means of suspension, the chance of this happening can be greatly minimized.

The power plant superintendent, C. C. Bush, of Union Bag & Paper Corp., Savannah, Ga., presented a paper prepared by himself and Glenn D. Farrar of the General Electric Co. on "Union Bag's Triple-Automatic-Extraction Turbine."

Mr. Bush, in discussing the world's first turbine of this kind, pointed out the reasons behind the decision to install such a turbine by Union Bag.

For details of operation and construction, reference is made to the full text of the paper which will appear later in *Tappi*.

The principal speaker of the evening was B. K. Steenberg, Research Director, Swedish Forest Products Research Laboratory, Stockholm, Sweden.

Mr. Steenberg's paper had to do with "Principles of Screening and Screening System Design." Mr. Steenberg has developed a new concept of screening and showed very clearly that all operations in which one material is separated from another are governed by the same physical laws which control the screening operation in the pulp or paper mill. He showed that the classical theory of probabilities would only hold in very dilute concentrations. In the normal consistency ranges, Mr. Steenberg has applied the theory of quantum mechanics to explain the operation of screens. He also pointed out that refiners which alter the physical size of the fibers are governed by the same laws. Mr. Steenberg finally showed, with the use of slides, several screening systems by which any desired degree of separation could be obtained.

Mr. Steenberg's paper will be published in conjunction with several others on the same subject.

C. L. Smith, *Recording Secretary*

Basket Cooking in Mill Digesters

W. M. Blume

This paper is entitled "Basket Cooking in Mill Digesters." Some of you have undoubtedly used this method of cooking in digesters before and have your own pet names to call it. Basket cooking in mill digesters was inaugurated at the Charleston mill of West Virginia Pulp & Paper, Co., in March, 1950. It was used to make a comparison between the pulping properties of two differently prepared pine chips. Since that time this method has seen extensive use for projects concerned with digester yields, uniformity of a cook within a large digester, and comparison studies between different types of wood.

The method itself is very simple and may be considered parallel to cooking small batches in a laboratory digester, but with far less work involved. It has many virtues which make it attractive. Besides simplicity, it is practical, economical, reliable, and above all versatile. Most of the equipment required for the method is usually part of the existing equipment of any pulp laboratory, such as a large accurate balance or set of scales, a pulp drying oven, a small laboratory refiner or defiberer, and pulp washing and pressing equipment. The other main piece of equipment is the container which can easily be fabricated to meet the requirements of the individual mill.

The procedure for basket cooking is relatively simple and requires only that several weighings and moisture determinations be made on the chips and pulp. The procedure for the use of this method in checking the yield of a mill digester is the most difficult one and requires the most time for preparation. First, a representative sample of chips is obtained as they are being charged into the mill digester to be checked. A predetermined height in the digester is selected where the basket will be placed and the chip charging operation is stopped at this level. The sample of chips is quickly and throughly mixed, and a weighed portion is charged into the basket or baskets as the case may be. Also a sample of the chips is placed in an air-tight container so that the oven-dry weight of the chips can be determined. The basket is then

W. M. Blume, West Virginia Pulp & Paper Co., Charlestown, S. C.

W. C. Chapman, Union Bag & Paper Corp.

B. K. Steenberg, Swedish Forest Products Research Laboratory

lowered into the digester by means of $^3/_8$-in. diam. steel cables that are of required length and are fastened to the basket on one end and secured to the bottom of the digester head on the other end. The digester charging operation is then continued and the cook accomplished in the usual manner. After the blow the digester head is removed and the basket or baskets are pulled out of the digester by use of the attached cables. It is necessary to defiber the chips and wash the liquor from the pulp. This can easily be accomplished with the heretofore mentioned equipment. The pulp yield can then be determined after determining the oven-dry pulp obtained. If small moisture samples are used rather than drying all of the pulp, this leaves enough pulp for any further evaluations that are necessary. The procedure for comparison studies and checking the uniformity of a cook is similar to the one just described with the exception that the chips can be charged into the baskets at any convenient time and the baskets can easily be placed in the digester at the first opportunity and cooked.

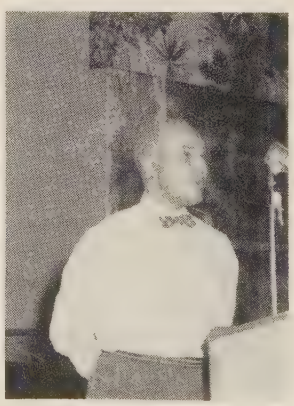
As was first stated this method of cooking has enabled us to determine digester yields and to study the uniformity of a cook throughout an entire digester. But by far it has been a valuable time saver where comparison data of pulp properties on certain woods were needed. As many as six different types of woods have been compared by this method with a single cook in a mill digester. You can readily picture the elaborate preparations and the work involved if such a project were undertaken in a laboratory digester. This type of cooking is considered to be a very reliable means of obtaining a comparison between pulps because each has received identically the same treatment and has been cooked under mill conditions which are not always so easily duplicated in laboratory equipment.

This method, like a good many others, has its drawbacks or disadvantages. The liquor charge or the soda demand cannot be precisely determined. Although in our $4^1/_2$ years of use we have never lost a single basket, the possibility of losing a basket in a digester thus causing down time, cannot be overlooked. This can be minimized by constructing the basket to withstand the rugged treatment it must undergo in the digester.

One very important requirement of this method is the selection of the correct size of wire material to be used to make the baskets. By this I mean that it is necessary to determine by trials the size openings that will not let any of the fiber pass in or out of the container, but that will still give the required circulation of the cooking liquor, thus producing identical cooking conditions within the basket as those within the digester.

The first baskets used at our mill were made of $^1/_8$-in. diam. perforated screen plate material, approximately $12^1/_2$ in. in diameter and 24-in. high. We have found that when cooking a pulp to a permanganate number below 30, TAPPI standard, and using these baskets that there was a definite transfer of fiber from the digester into the basket.

C. C. Bush, Union Bag & Paper Corp.



W. M. Blume, West Virginia Pulp & Paper Co.

B. K. Steenberg, K. M. Guest, M. L. Taylor, and J. R. Lientz

After a very intensive investigation using baskets such as described here we were able to select the correct size of material to use at our mill. (Description of small baskets—A, $^1/_8$-in. diam. perforated screen plate; B, 14-mesh wire with 0.015-in. openings; C, 40-mesh wire with 0.050-in. openings; and D, 100-mesh wire with 0.0058-in. openings used as a liner for basket A. These small baskets were charged with chips and then placed in one of the larger $^1/_8$-in. perforated baskets. The larger basket was suspended in the digester for the cook.)

Eleven tests were conducted in this manner and the permanganate number of the pulp from the 40-mesh wire basket came within one unit of the average permanganate number of the entire digester.

It was also discovered from these tests that the permanganate numbers of the pulp from an individual digester would vary as much as 4 units, but permanganate numbers of the pulp from the 40-mesh basket deviated less than 2 standard deviations from the digester average.

Since this investigation we have constructed several small baskets of 40-mesh wire approximately 1 cu. ft. in volume, 7 in. in diameter by 18 in. high. This basket will fit very nicely into the large $^1/_8$-in. perforated basket and about 1000 grams of pulp can be obtained from this size basket.

At the beginning of my talk several claims were made concerning the basket method of cooking in mill digesters. As can be seen from the preceding the method is quite simple and requires only several simple tests and calculations which the average person can readily do. The method is practical because it causes no interruptions or lost time from production. It requires no attention from the time the digester is charged until it is blown. The method is also very economical; the major cost being the initial construction of the containers, presuming of course that pulp lab facilities are available. It has reduced the work in certain studies by three to four times that required if the same studies were made in a laboratory digester. It has proved to be a reliable method as it compares very favorably with data obtained by a different method of cooking. It has been found to be very versatile in that it can be used for many different studies, three of which I have named.

In closing I would again like to point out the importance of selecting the correct size of container openings so that the data obtained can be reliable; for I believe that this will vary from mill to mill and possibly within a mill itself where different types of pulp are produced.

It is my hope that some of you will find an application for

Southeastern Section dinner, smorgasbord style

the method and utilize it. It has been very useful at our mill and will undoubtedly continue to be.

Ohio

The Ohio Section of TAPPI held its second meeting of the 1954–55 season in connection with the Fifth Testing Conference which was held at the Hotel Biltmore in Dayton, Ohio, on Thursday evening, Oct. 7, 1954. It was indeed an honor for the Ohio Section to be the host at a joint meeting with the Ohio Section of ASTM as well as the host for the testing conference banquet.

Harold Joiner, chairman of the Ohio Section, welcomed the group and introduced the officers of Ohio ASTM and of the testing conference as well as many visiting dignitaries.

Virgil Perry of Harding Jones Paper Co. introduced Carl Ludeke, associate professor, Department of Physics, University of Cincinnati, who was the speaker of the evening.

Mr. Ludeke spoke on the subject "Atomic Energy Applied to Industry," which was an interesting talk on the history and future of atomic energy. Mr. Ludeke did an outstanding job of discussing such a technical subject.

Perhaps the most important aspect of the application of atomic energy to industry is the speed with which it has entered the industrial phase. It wasn't until 1932 that the third of the basic building blocks of nature was discovered. With the advent of the neutron in 1932 together with the already known electron and proton, a scheme could be devised which indicated the possibility of transmutation of the elements. Six years later in 1938 a type of transmutation known as a fission was discovered. In this process the bombarded nucleus break into two relatively equal parts plus extra neutrons. The fact that there were extra neutrons available to bombard adjacent nucleii gave birth to the idea that once the first nucleus was split by a neutron the extra neutrons could maintain the process; thus the possibility of a chain reaction. In 1942, scarcely 10 years after the neutron was discovered, these same neutrons were performing in a controlled chain reaction at Chicago. Of course, this was in a laboratory, but we read that in 1957, only 15 years after the first laboratory experiment, the Duquesne Light & Power Co. will have in operation a large commercial station for generating light and power, the entire plant to be operated by atomic energy from nuclear reactors. To move from the laboratory to industry, with such a fundamental and complicated reaction as fission, in 15 years, is indeed a credit to both science and industry . . . and certainly this is only the beginning.

Mr. Ludeke left all those present with a better understanding of atomic energy, its problems, and its future.

E. W. Petrick, *Recording Secretary*

RECENT BOOKS

Cellulose and Cellulose Derivatives. Part I. 2nd Ed. Edited by Emil Ott and Harold M. Spurlin, Research Dept., Hercules Powder Co. Interscience Publishers, New York, 1954. Cloth, 6 × 9, 509 pages. $12.

The present volume is No. 5 in the High Polymer Series of Interscience Publishers. The first edition appeared in 1943. With the passage of more than ten years marked development has occurred in fundamental concepts of the subject, and sufficient new experimental data have accumulated to justify a complete reworking of the first edition.

Among the individuals who contributed to Part I are the following members of TAPPI: F. E. Brauns, Institute of Paper Chemistry, James d'A. Clark, Consultant; R. S. Hatch, Hudson Pulp & Paper Co.; W. F. Holzer, Crown Zellerbach Corp.; Harry F. Lewis, Institute of Paper Chemistry; A. T. Maasberg, Dow Chemical Co.; H. Mark, Polytechnic Institute of Brooklyn; A. F. Martin, Hercules Powder Co.; Clifford B. Purves, McGill University; George J. Ritter, Eastman Kodak Co., S. D. Wells and Kyle Ward, Jr., Institute of Paper Chemistry.

Among the subjects covered are: Occurrence of Cellulose, Chemical Nature of Cellulose and Its Derivatives, Structure and Properties of Cellulose Fibers, Properties of Substances Associated with Cellulose in Nature, Preparation of Cellulose (Pulping), Bleaching and Purification Properties and Treatment of Pulp and Paper, and Tests.

The Story of Papermaking. By Edwin Sutermeister. R. R. Bowker Co., New York, 1954. Cloth, $6^1/_2 \times 9^1/_2$, 220 pages. $5.00.

Every now and then it becomes possible to induce a competent person to put his nose to the grindstone and produce a much needed work. Too often too many individuals are too lazy to do a job that should be done. Dr. Sutermeister, the author of the present text, admits that the constant urging of his associates at the S. D. Warren Co. induced him to prepare a book that would be written as a technical man could write it and as a layman could understand it.

The chapters of the book include such titles as materials for records, nonwoody fibrous materials, wood, groundwood, the soda sulphate, sulphite, and other processes, bleaching, stock preparation, the paper machine, coating, calendering and finishing, and paper grades and definitions.

The book was written for students, apprentices, paper salesmen, and others who wish to learn about the industry as painlessly as possible. There have been many books written on the subjects by individuals who know little or nothing about the industry. Dr. Sutermeister has performed a real service. Even technically trained men familiar with more complex texts will enjoy reading this book and will be surprised to obtain information that they do not already have.

The Practice of Silviculture. 6th Ed. By Ralph C. Hawley and David M. Smith, Yale University. John Wiley & Sons, New York, 1954. 6 × 9, 525 pages. $7.50.

The sixth edition of this standard text is a successor to the 1946 volume. During the interim more progress has been made in the application of forestry than in the previous four decades. The 50% expansion in the number of pages reflects this progress.

Emphasis is given to enhancing the productivity of the forests and the authors have made more than an ordinary effort to answer the question "Why?."

Among the subjects covered are the clear-cutting method, the seed-tree method, the shelterwood method, and the selection method, slash disposal and prescribed burning, intermediate cuttings, thinnings, and priming.

The book is too widely used to need much editorial comment. The rapid advance in the knowledge of silviculture makes it necessary for individuals interested in woodlands to keep up to date as this book succeeds in doing.

The Technology of Solvents and Plasticizers. By Arthur K. Doolittle, Assistant Director of Research, Carbon & Carbide Chemicals Co. John Wiley & Sons, New York, 1954. Cloth, 6 × 9, 1056 pages. $18.50.

It is obvious that there were many years of research and writing on the part of the writer in the preparation of this text. It is written primarily for the paint and plastics industries but with the constant extension of paper into nearly every field of endeavor its contents are of interest to many paper converters. The book relates to applications of solvents and plasticizers in surface coatings, plastics, synthetic fibers, adhesives, and inks.

Important chapters include nitrocellulose lacquers, vinyl resin coatings, convertible coatings, and the technology of application. Two chapters are devoted to plasticizers. Theoretical discussions cover solvent action, viscosity, and the thermodynamics of polymer solutions.

An interesting aspect of the sale of this book is the use to which royalties will be put. They will be used to finance the Carbon & Carbide Chemicals Award which is administered by the Paint, Plastics and Printing Ink Division of the American Chemical Society. The award will be given each year for the outstanding scientific contribution reported in a technical paper before a regular meeting of the section.

Pulp and Paper Manual of Canada—1954. National Business Publications Ltd., Gardenvale, P. Q., Canada. Pyroxlyn, 8 × 11½, 446 pages. $7.50.

The 22nd edition of the "Pulp and Paper Manual of Canada" continues to maintain the high standards established and followed by its editor, J. N. Stephenson.

Aside from the large number of page advertisements which feature the products used by Canadian mills, there are flow diagrams of several pulp and paper mills and articles on instrument panel selection, open-gear lubrication, European log hauling machinery, chips from logging operations, and many engineering data sheets.

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P411-54. Mechanical Engineer for new and expanding pulp mill in Southeastern North Carolina. Must have had from 3 to 6 years' experience in the pulp and paper industry and be capable of doing layouts, design, cost estimating, reports, and engineering field work under general supervision only. Benefits include generous insurance, vacation, and retirement plans. Salary commensurate with qualifications. Please make résumé as complete as possible and submit a recent photograph.

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Sixth Coating Conference, Statler Hotel, Cleveland, Ohio, May 23–25, 1955.

Second Mechanical Pulping Conference, Poland Spring House, Poland Spring, Me., September 19–21, 1955.

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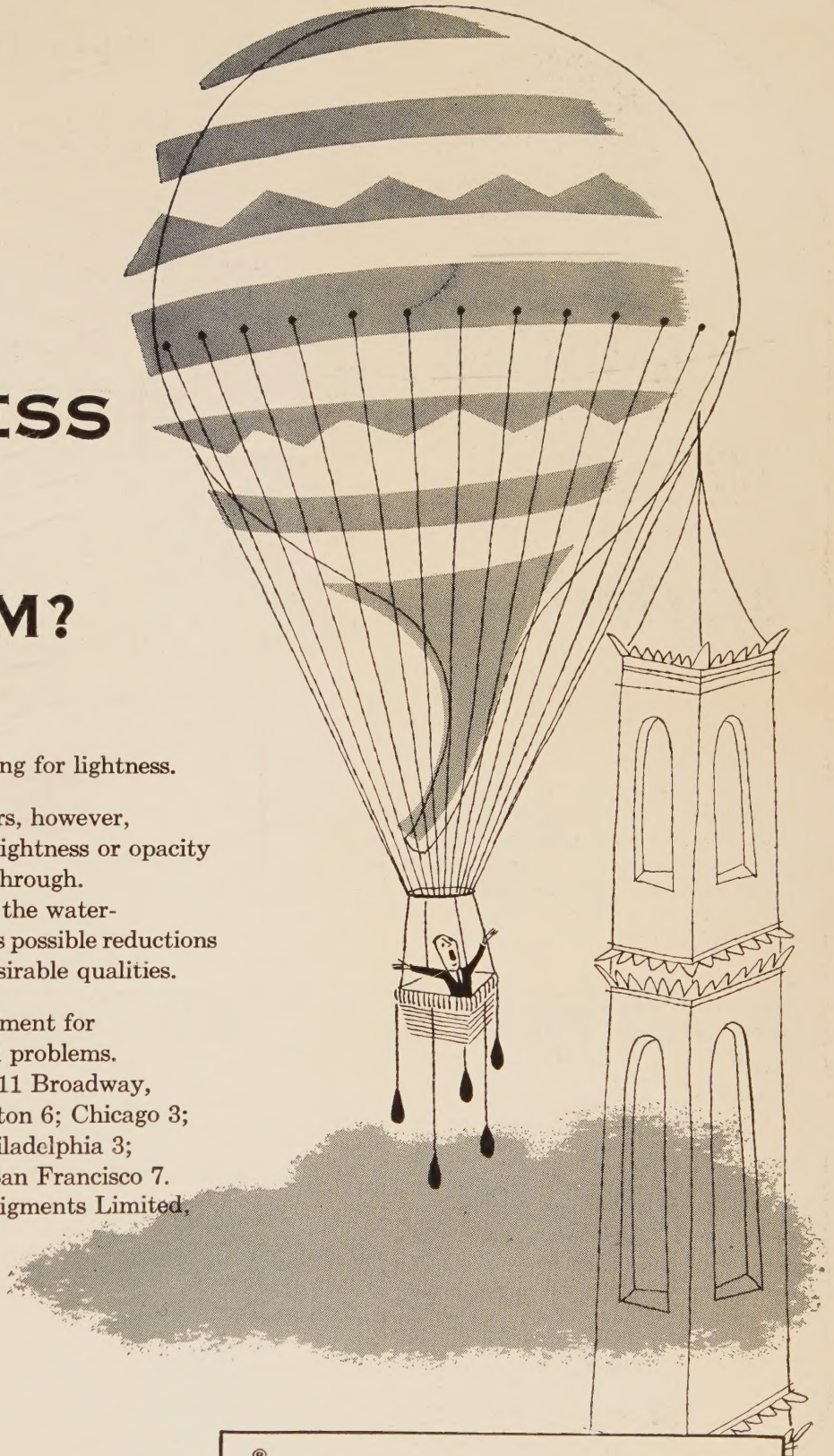

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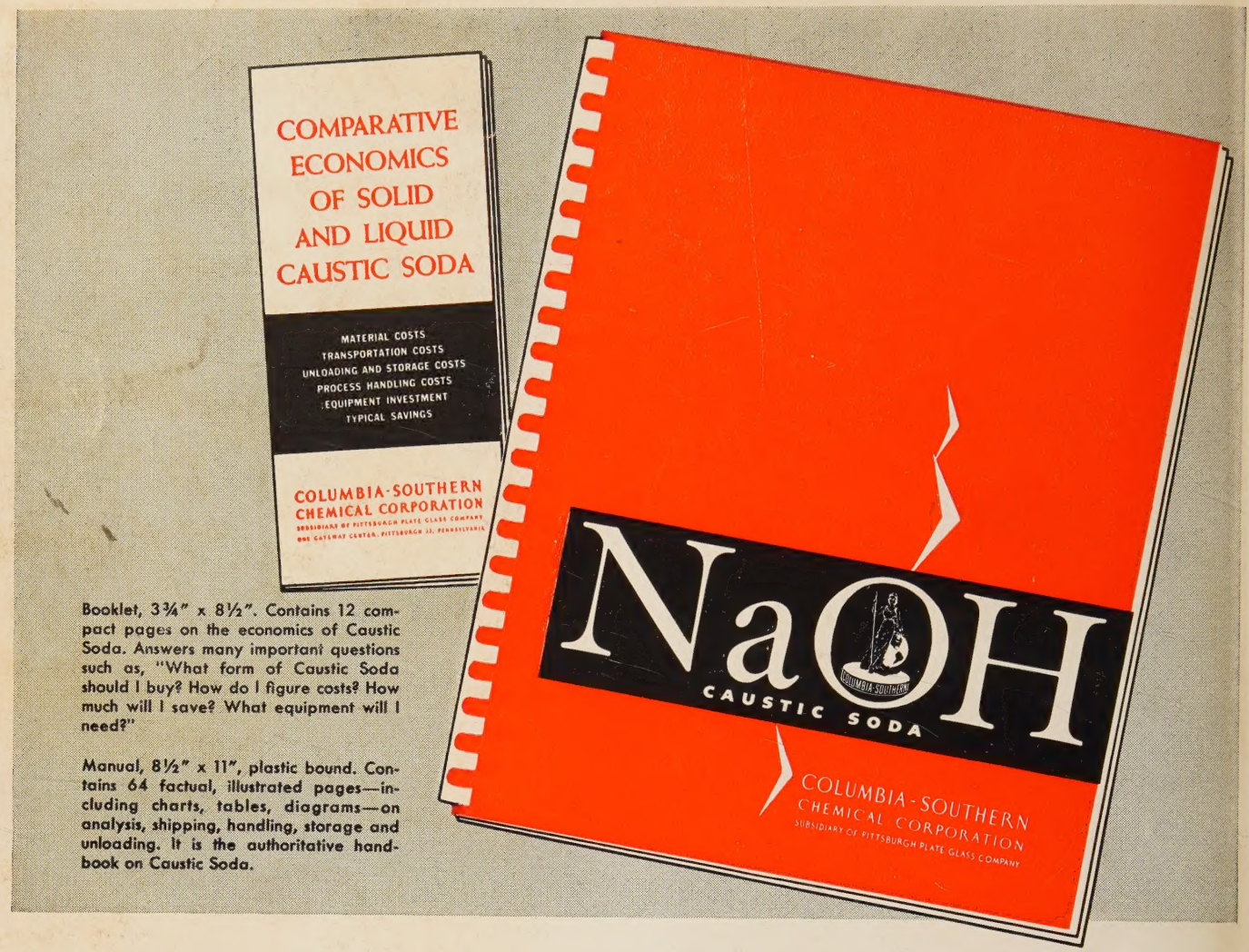

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